01 November 2016

Cambridgeshire Guided Busway

Advisory Report on Guideway Investigations, Defects and Corrective Measures

Cambridgeshire Guided Busway
Cambridgeshire County Council v BAM Nuttall Ltd.

Advisory Report on Guideway Investigations, Defects and Corrective Measures

Instructed	:	Tony Cort / Robin Sanders
	:	
For	:	BDB
	:	Cambridgeshire County Council
Date	:	1 November 2016
Ref	:	CS/059090

This document is for use solely by our Client and its legal team in providing preliminary advice following investigations carried out to further understand the behaviour of the guideway.

Drafted : Tony Cort, Andy Hallum, and Robin Sanders

Checked : Claire Clark

CONTENTS

INTRODUCTION

Instructions

1. This report follows an earlier report dated 11 September 2014 that was addressed to elected members of Cambridgeshire County Council (‘the Council’) which examined notified Defects on the Guideway, explained why the defects need to be addressed, and described options that we considered appropriate at that time for correcting the Defects. This led to a subsequent decision of the Council and BAM Nuttall (‘BAMN’) to carry out additional investigations that would further inform the parties in understanding the reasons for the Defects that had been observed. Those investigations have now been carried out, although certain investigations, namely thermal monitoring to determine expansion/contraction movements and levelling to determine foundation movement, are ongoing. The results of these ongoing investigations (called H and J respectively) are unlikely, however, to affect the conclusions in this report.

2. This second report is for issue to elected members of the Council. It has been prepared by us, Messrs Tony Cort and Robin Sanders, as independent engineering experts instructed by the Cambridgeshire County Council’s (‘CCC’) solicitors Bircham Dyson Bell (‘BDB’). We acknowledge that we have been assisted by Andy Hallum BSc(Hons), CEng, MICE, MIStructE, ACIArb and Darren King BSc, MSc, FGS, CGeol, CEng, CEnv, MIMMM, ACIArb who have carried out under our supervision supporting reviews, calculations and analyses. The Curriculum Vitae of Tony Cort, Andy Hallum, and Robin Sanders are enclosed in Appendix A.

3. The report informs elected members of the development of our opinions following receipt of the results of the additional investigations. These investigations have been on the northern section of the busway, between St Ives and Milton Road, and were funded by CCC and BAMN and administered by Skanska under two investigation contracts. Our opinions herein relate to specific notified Defects on the superstructure (i.e. the elements of the guideway above the foundations) on the entirety of the guideway and notified Defects on the foundations on the northern section of the guideway, i.e. between St Ives and Milton Road, Chesterton. The ground conditions on the southern section of the guideway, from Cambridge Railway station to Trumpington and Addenbrookes hospital are different to those for the northern section and, at this time, are not considered to have the potential for an adverse impact on the guideway.

Report contents

4. The advisory report:

    (i) summarises the September 2014 report;

    (ii) describes the investigations which were undertaken on the guideway;

    (iii) describes the conclusions we have drawn from the investigations;

    (iv) describes the Defects we are considering in outline;

    (v) summarises the reasons why it is necessary that something is done about the Defects;

    (vi) explains what, in our opinion, could happen to the guideway over time if nothing is done to correct the Defects;

(vii) reassesses the remedial works outlined in the September 2014 report;

(viii) explains what, in our opinion, are the options available to the CCC to correct/manage the Defects, covering both pre-emptive repairs, reactive repairs when the effects of Defects manifest themselves and both pre-emptive and reactive work that will, in part or in whole, alleviate or reduce the effects of the Defects.

5. Mr Cort has prepared the sections of this advisory report that discuss the investigations that relate primarily to the performance of the superstructure (i.e. Investigations A, E, H & I carried out by Strainstall, Investigation G carried out by BICS, Investigations B, C, D & F carried out by Survey Solutions, and Investigation K carried out by Skanska. Mr Sanders has prepared the sections of this advisory report that relate to foundations and ground conditions on the northern section of the guideway. This includes Investigation J undertaken by Survey Solutions and, funded solely by BAMN. This later investigation is still being carried out. It comprises the monitoring of beam movement over approximately monthly intervals on selected parts of the guideway to aid assessment of possible foundation movement due to seasonal and/or vegetation related changes in ground conditions particular ground moisture contents.

SUMMARY OF SEPTEMBER 2014 REPORT

6. By way of summary, our report dated 11 September 2014 contained:

7. For the superstructure:

(i) A description of the construction of the guideway including details of the various elements;

(ii) A description of the Defects that exist within the guideway detailing an extensive scope of the remedial works or repairs required to the guideway to rectify the Defects;

(iii) Consideration of potential remedial works options to correct the Defects to the guideway itself that have collectively been given the overarching title of 'Grand Unified Defect' (GUD). A major problem is that bearings and shims continue to displace and come out and steps greater than the permitted tolerance of 2mm are arising in the guide face of the guiderails (see Figure 2 on page 7). There are other miscellaneous notified Defects that require correction which are not within our brief;

(iv) Outline and preliminary details of the potential remedial works (three options) based on information available at that stage;

(v) Option 1 pre-emptive remedial works. In essence, this involved the bearing pads being fixed in place and the shims arranged so that they do not slide out and are able to take a proportion of the horizontal load that the guideway is required to accommodate. For this Option, the guideway would have been closed in sections to carry out the remedial works with the details for this remaining to be fully assessed in conjunction with the Council and the bus operators. The estimated timeframe to carry out these works was 30 to 36 months, including proposed remedial works to foundations;

(vi) Option 2 reactive remedial scheme. This consisted of implementing the Option 1 proposals on a piecemeal basis. Should one or more bearings and/or shims slip out resulting in a step in the guideway running surface, this would trigger remedial works being carried out to a 30 metre section. It was expected that the remedial scheme would be protracted and could extend over the remaining life of the project i.e. 35 years to complete;

(vii) Option 3 scheme of reactive repairs. This comprised relocating the bearing pads/shims (but not fixing them in place) into the original design position when steps appeared in the running surface of the guideway together with repairing concrete spalling and other issues. We anticipate that the work would be carried out in the manner adopted for the emergency repairs to bearings, i.e. jacking up the guiderails to access the bearing pads and shims in order to relocate them. . The bearing pads and shims remain unfixed. It did nothing to prevent the pads/shims continuing to slip out, nor did the Option correct the Defects that in our opinion were inherent in the design.

(viii) Cost estimates for Options 1, 2 & 3 were prepared by Mr Chris Ennis of TQEF.

(ix) The report considered the merits and demerits of the superstructure remedial works options.

8. For the foundations:

(i) A discussion of the background to the foundation Defects;

(ii) An assessment of the required depth of all the shallow foundations on the northern section of the busway based on the potential growth of trees in close proximity to the guideway during its design life, and BAMN's zonation of ground conditions. The assessment considered two scenarios, firstly compliance with the contractual requirements to construct to the recommended depths given in NHBC design guidance for shallow foundations and a second scenario based on the BAMN's stated maximum capacity for the guiderails to deflect in response to differential settlement between the foundations without impairment of the guiderail's required performance,

(iii) A listing of those shallow foundations that have been constructed to an inadequate depth for both above scenarios, with a estimate of when the defective and inadequate foundations may display unacceptable movements.

(iv) The most reasonable and practical means of undertaking work to correct or nullify the effects of the foundation Defects;

(v) An outline and preliminary details of the remedial works (three options, A, B & C) based on information available at that stage;

(vi) All options dealt with the assessed future effects of trees planted as part of the guideway construction work by recommending pre-emptive arboricultural works and an enhanced arboricultural maintenance regime. All options also included pre-emptive foundation deepening works for the foundations between chainages 17510 – 17645 and chainages 17691 – 17811 due to excessive movements that had already occurred to most of the foundations along these sections

(vii) Option A full pre-emptive works. Consideration of the two scenarios described in (ii) above. Scenario 1 remediate all 868 foundations which did not comply with NHBC recommended depths thus placing the Council in the position it would have been if it BNL had constructed the works in accordance with the contractual requirements. Scenario 2 remedying a reduced number of such foundations, 643, allowing up to 25mm of differential foundation settlement with only a slightly heightened risk to the Council of future damage.

(viii) The application of the latter approach under Option A may possibly have been a slightly conservative approach in respect of the number of foundations that would, with time, move sufficiently to develop excessive differential movement between them. This was because of an inherent uncertainty as to how the roots of the trees would develop with time and thus precisely how many, and which, of the foundations assessed as requiring remediation by pre-emptive works, would move such that the differential movement between adjacent foundations would definitely be sufficient for deflections on the guiderails to become excessive.

(ix) Option B was essentially a 'half way house' between Options A and C (see (viii) below for Option C). It pre-emptively remediates the foundations assessed as being at greatest risk of excessive differential movement, many of which could be expected to show such movement in the next 10 – 15 years if not remediated. It thus significantly reduced the amount of reactive remedial works in those early years but only slightly reduced the amount of reactive remedial works in subsequent years. It reduced the impact on the temporary works methodology and programming of the remedial works Option 1 for the GUD and environment impact inherent in Option A. The option, however, required long term monitoring to occur and predicted significant reactive remedial works could be necessary over the remaining life of the guideway. Accurate prediction of when such reactive remedial works would be required was not feasible and thus forward year-on-year budgeting for such reactive remedial works would not have been possible. Additionally, as the expected effective life of the root barrier form of remedial works was around 20 years, a second phase of remediation would be necessary in the final years of the life of the guideway. This second phase would include a significant number of root barriers that would fail to halt differential movement and in such cases foundation deepening was likely to be required as a third phase of remediation.

(x) Option C was a wholly reactive approach. Remediation would only address the inadequate foundation depths when monitoring revealed that excessive differential movement was being approached. There would be no impact on the GUD remedial works programme and temporary works and a reduced environmental impact over the other two options. As with Option B, prediction of when such reactive remedial works would be required and forward year-on-year budgeting for such works was not feasible. As the expected effective life of the remedial works was around 20 years, a second phase of remediation would be necessary in the latter half of the life of the guideway. This second phase would include a significant number of root barriers that would fail to halt differential movement and in such cases foundation deepening is likely to be required as a third phase of remediation. As Option C would have the 105 additional 'very high risk' foundations being remediated reactively there would be considerably more on-going disruption to the operation of the guideway than with Option B in the forthcoming 10 – 15 years. The report advised that if the Council was adverse to the environmental impact associated with Option A and/or wished to minimise the frequency of closure of the guideway during its life and could accept additional risks inherent with reactive remedial works, as summarised below, Option B was recommended. The report advised there was a risk that 14 'high risk' and 235 'at risk' foundations on clays particularly prone to shrinkage may move in excess of 25mm during the first period of significant movement. This could compromise the durability of overlying guiderails.

(xi) The report discussed the merits and demerits of the foundation remedial works options and considered the combination of options for the superstructure and foundations.

DESCRIPTION OF GUIDEWAY

9. The guideway is formed of three principal elements

   (i) the foundations;

   (ii) the concrete elements which should provide a stable running surface ('guiderails') and guidance for the buses; and

   (iii) the supports between these two elements, which are formed of bearings and shims.

10. The guiderails are made of concrete and have upstands on the outer edges which keep the buses on the track. The guiderails are kept apart by spacer beams that are bolted to the guiderails, thereby forming a series of 'ladders'. The arrangement is shown in the photograph below.

Figure 1. Photograph of a section of the guideway showing the spacer beams and foundation pads.

11. Ladders are 10 or 15 metres long (mostly 15 m) and are supported at each end and in the centre by foundations. The rails rest on plastic (high density polyethylene) shims, which in turn rest upon elastomeric (rubber) bearing pads. These sit directly on a raised upper surface of the foundation pads or pile caps.

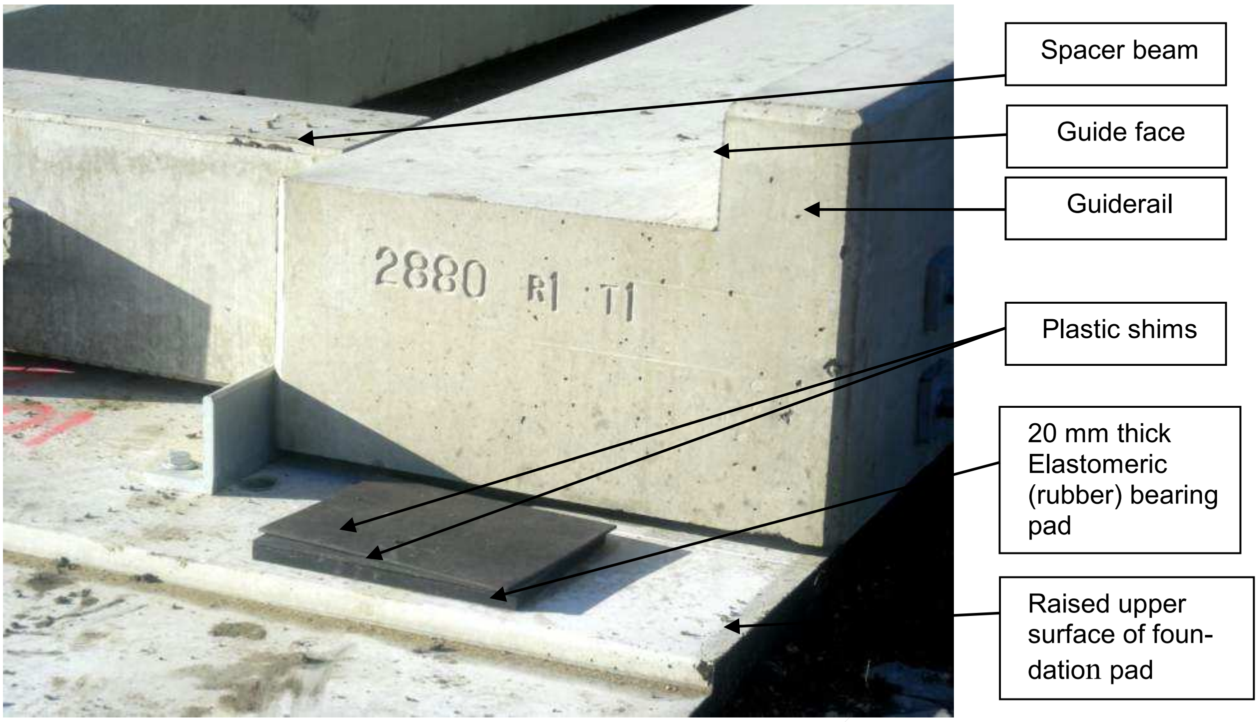

Figure 2. Photograph of a part of the guideway during construction, showing a spacer beam, guiderail, shims, bearing pad, and foundation pad.

12. The shims are the only part of the guideway structure that are designed to be removed or added to allow limited vertical movement between the foundations and guideway ladders. The individual shims are of 2mm and 5mm thickness so that small, millimetre scale adjustments can be made to ensure the continuity of bearing between the guideway ladders and the foundations.

13. The elastomeric (rubber) bearing pads are present to provide uniform seating of the beams and to permit the ends of the guiderails to rotate without damage occurring to the concrete. Such rotation occurs when buses pass along the guiderails causing them to move downwards slightly, and also when one foundation of a guiderail moves vertically relative to the next foundation – the design was supposed to allow for 25mm of such differential movement of the supports.

14. BNL's design included for there to be 10mm of shims in place on construction and permitted a maximum of a further 25mm to be placed if necessary. Limited exploratory excavations to examine the bearings and shims along the site, where no previous adjustments have been made, have shown that the depth of shims present is variable where shallow foundations are present. We believe this reflects corrections to the level of the guideway undertaken by BNL prior to handover to the Council. There appears to be no correlation between depth of shims and shallow foundations or ground conditions, the overall shim thicknesses probably being a function of how accurately in level the foundations were installed. The depth of shims occasionally exceeds BNL's design limit of 35mm as can be seen in the photograph below.

Figure 3. Photograph of a foundation pad upon which there are more than 35mm of shims.

15. Alternate joints in the ladders are designated as 'fixed' and the guiderails at these locations are designed as touching end-to-end. At these locations both ladders were 'fixed' by brackets positioned against the spacer beams and bolted to the foundation pads or pile caps. These brackets are intended, according to DDG Rev 6, to provide restraint to longitudinal movement of the ladder units under a longitudinal force of about 24 tonnes.

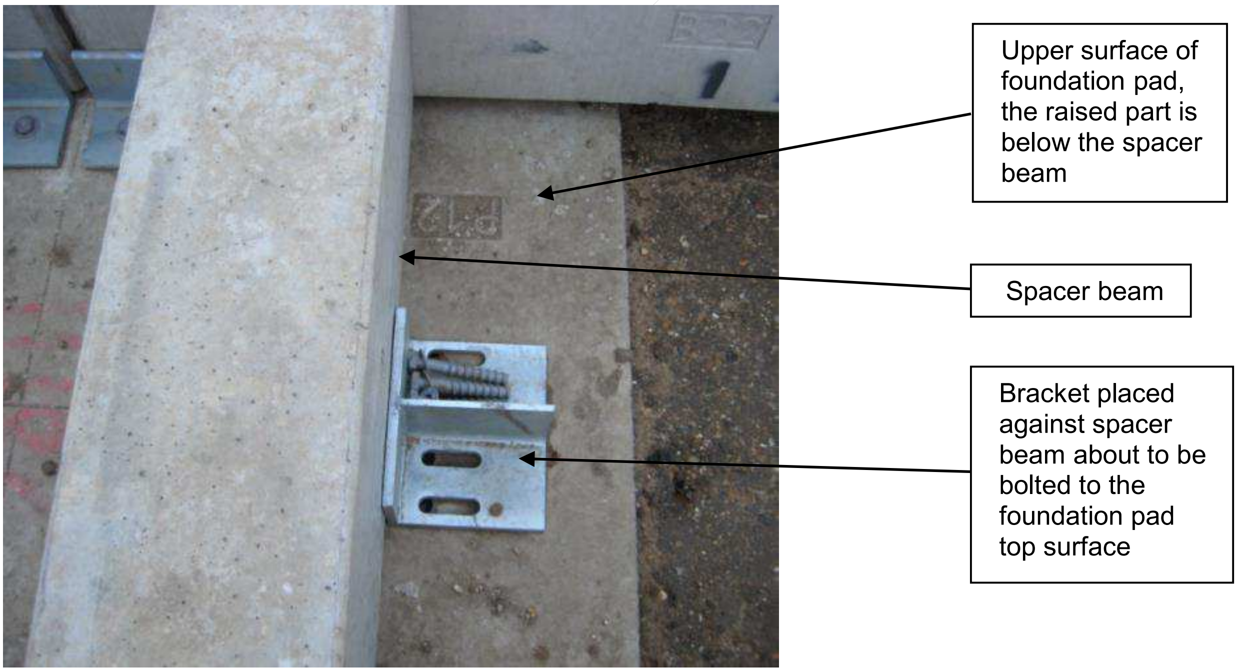

Figure 4. Photograph of a 'fixed' joint longitudinal restraint bracket.

16. The other joints between the fixed joints are not 'fixed'. They were designed to allow longitudinal movement arising from temperature changes which cause expansion and contraction of the ladder units. These joints are called 'free' joints.

17. The beams are designed to be restrained laterally (across the direction of bus travel) by brackets that are placed against the inside of the guiderails at every joint.

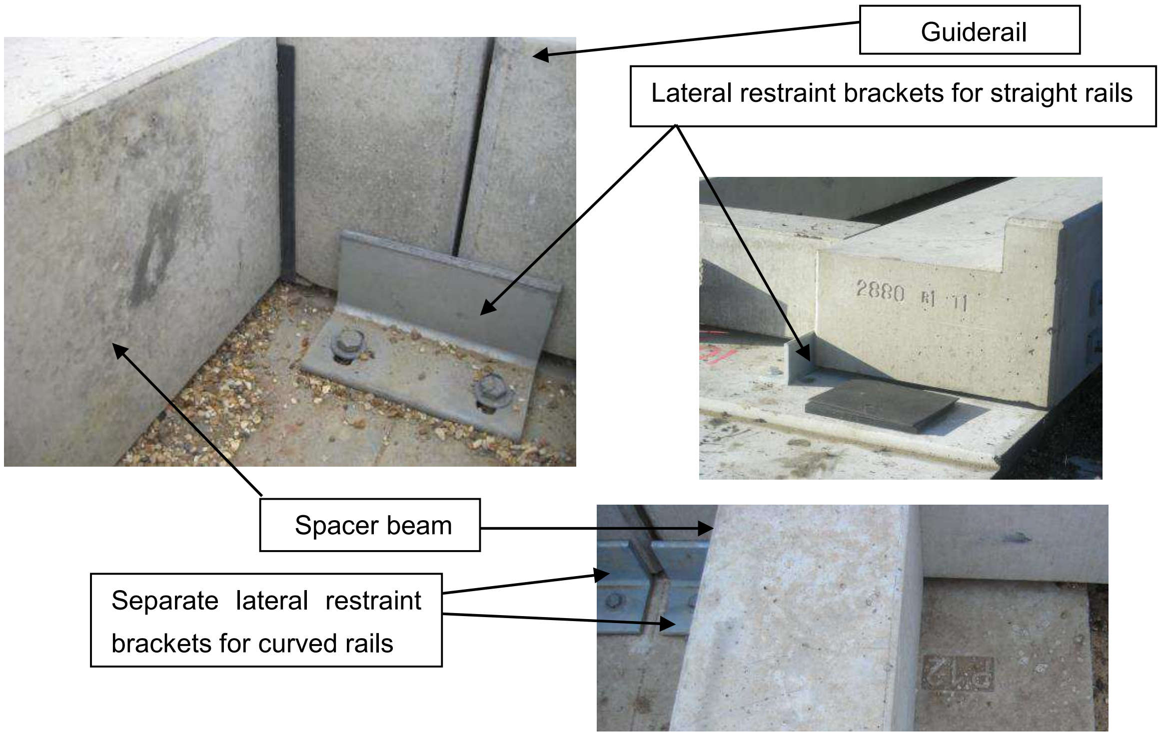

Figure 5. Photographs of lateral restraint brackets.

ADDITIONAL INVESTIGATIONS

18. Investigations were carried out to provide a better understanding of the performance and behaviour of the as-constructed guideway:

   (i) in relation to its stiffness characteristics and the implications of this;

   (ii) in providing a definitive record of the extent of alleged steps (longitudinally and transversely), concrete spalling, concrete cracks, spacer movements, and joint widths;

   (iii) in identifying the frictional properties of the shims and elastomeric pads;

   (iv) in investigating any bearing/shim movements;

   (v) in obtaining levels of the guideway at certain locations including foundation level monitoring;

   (vi) in monitoring thermal expansion/contraction; and

   (vii) in monitoring the performance of the guideway under braking of a fully-loaded bus.

19. The investigations are described in the following paragraphs:

20. **Investigation A**. This investigation, carried out at three locations, was designed to assess the stiffness characteristics of the guideway ladder assembly i.e. the superstructure. It comprised raising and lowering the structure at various points close to the bearing support positions and loading the guideway with a vehicle of known weight, whilst recording the support reactions and ladder deflections/movements.

21. **Investigation B.** This investigation involved bearing surveys at the January 2014 boroscope[1] photographic survey of bearings at Longstanton (chainages 10946 to 11141 Cambridge-bound track) with associated levelling surveys. The intent was to compare the results with the 2014 bearing surveys.

22. **Investigation C.** This investigation comprised a walkover survey to record visual defects such as vertical and horizontal steps at joints, spacer beam movements, and spalling.

23. **Investigation D.** This investigation consisted of levelling the guideway ladders at various locations to assess any distortion of the structure in terms of out-of-planeness. Each ladder is supposed to be assembled and put in place such that the running surface of the two guiderails form a single plane with no twist or bend in the ladder.

24. **Investigation E.** This investigation involved testing the lateral restraint brackets to assess their resistance to movement, since we considered this to be potentially inadequate. This was carried out by jacking opposite brackets apart, involving four pairs of brackets each with two bolt holes, at two locations. Some included packer plates beneath the brackets. Tests were carried out with one of the brackets fixed with either one bolt or two bolts.

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[1] A boroscope is an optical device consisting of a rigid or flexible tube with an eyepiece or camera on one end and an objective lens on the other. It facilitates examination of the otherwise inaccessible bearings/shims.

25. **Investigation F.** This investigation was similar to Investigation B except that the surveys were carried out at 60 discrete beam end chainage locations (105 ladder ends) along the guideway (selected using information from investigation C but with no comparison being undertaken with previous surveys. The primary intent was to assess the reason for the vertical steps between guideway ladders that have been recorded.

26. **Investigation G.** This investigation comprised testing the frictional coefficients of the shims against concrete, elastomeric bearing pads and other shims, and the frictional coefficients of elastomeric bearing pads against concrete. Original and replacement (new) shims were tested. Selected material property testing was undertaken to compare original and new shim properties.

27. **Investigation H.** This investigation is monitoring over time the thermal movements and air/concrete temperatures of the guideway at two separate locations (at the time of writing, this investigation has been in progress since the beginning of 2015 and is ongoing).

28. **Investigation I.** This investigation consisted of brake tests using a fully-loaded double decker bus and was carried out at three locations, two where the superstructure is supported on pad foundations and one at screw pile foundations. This included recording the performance of the guideway from a bus travelling at its maximum speed with the brakes then applied sufficiently hard (as in an emergency) to operate the bus's anti-braking system. This would generate the maximum braking force that would be expected to be applied to the guideway in the operational condition assuming no skidding occurred.

29. **Investigation J.** This investigation consists of monitoring the level of each guiderail's running surface directly above 181 selected foundation pads between chainages 6343 and 19993 where there is a perceived high to very high risk of future foundation movement. A template was used at each location, with the objective of identifying vertical height changes over time due to changes in seasonal weather patterns. BAMN proposed the surveys and selected a number of locations. Capita's expert Mr Sanders also selected a limited number of locations based on the assessment of foundation compliance at the time of the investigation specification. This investigation is currently continuing on a monthly basis.

30. **Investigation K.** This investigation was carried out to assess concrete damage at the bottom of the joints in the guiderails at all locations where excavation had been carried out for Investigations B, E, F and I. In addition, the survey was extended in August 2016 to record the situation at other random locations.

Timing of Investigations.

31. The investigation site operations were carried out on the following dates:

Investigation A

Location 1: 08.11.2015; Location 2.1: 29.11.2015; Location 3: 06.12.2015; Location 2.2: 13.12.2015.

Investigation B

B1 (Photographic survey) First Survey 11.10.2015; Second Survey 15.12.2015.

B2 (Level survey) First Survey 13.10.2015; Second Survey 15.01.2016.

Investigation C

Survey 15.09.2015 to 09.11.2015.

Investigation D

Survey 10.11.2015 to 03.12.2015.

Investigation E

Testing 08.12.2015 to 14.12.2015.

Investigation F

F1 (Photographic survey) 14.12.2015 to 19.12.2015.

F2 (Level survey) 14.12.2015 to 17.12.2015.

Investigation G

Laboratory testing 14.10.2015 to 19.11.2015.

Investigation H

Installation 02.10.2015 to 04.10.2015; On-going information being received since then on daily basis via data logger.

Investigation I

Location 1: 18.10.2015; Location 2: 31.01.2016; Location 3: 17.07.2016.

Investigation J

First Survey including survey station installations: 22.09.2015 to 08.10.2015 (No template used).

Subsequent surveys approximately monthly using a locating template to provide reliable repeat survey comparisons from 21.10.2016 and ongoing at the time of writing.

Investigation K

Inspection survey 02.02.2016 to 04.02.2016.

Additional Inspection Survey 23.08.2016 to 24.08.2016

WHY BEARINGS AND SHIMS ARE COMING OUT – THEORY

In-Plane Guideway Ladder

32. By 'in-plane' we mean that the longitudinal gradient of a ladder is constant over the three pairs of supports and that any difference in level transversely across the two guiderails (which is actually supposed to be zero because there should be no superelevation[2]) is also constant. In other words, the guiderails are straight and there is no twist in the ladder.

33. The design intent is clear from the Contract requirements. The Contract Specification 2100 contains a Bearing Schedule (based on BS 5400 Part 9) and states that the type of fixing for the bearings is 'Friction' assuming that the coefficient of friction between bearing and upper or lower surface is a minimum of 0.4 and the coefficient of friction between shims is also a minimum of 0.4. In addition, DDG Rev 6 Appendix A refers to BS 5400 Part 9 as the definitive requirement for the design of bearings. In our opinion, therefore, the contract requires the guideway bearings to be designed to BS 5400 Part 9.1 and the Works Information requires the elastomeric bearings to be tested in accordance with BS 5400 Part 9.2 (see Contract Appendix 1/5).

34. The design intent is also evident from the Maintenance Manual BAM137A/CGB/MM/09 Rev 6 which states at section 3.4.1,

> *"On the mainline guideway, the beams rest on plain non-laminated elastomeric bearing pads at each support position allowing free rotation and translation. The bearing pads are not fixed to the beam or foundation, friction being adequate to prevent relative movement."*

It also states,

> *"The adjustment shims also rely on the weight of the beams and friction to prevent relative movement between the interfaces. The shims were surface roughened to provide the required coefficient of friction for this element of the design. Bearings and shims are expected to remain in service for the design life of the guideway."*

35. The total weight of a 15m long guideway ladder is in the order of 305kN (30.5 tonnes) and the end support reactions[3] are approximately 32kN (32 tonnes). A support (or bearing) comprises a combination of elastomeric pad plus several adjustment shims, see paragraph 11 and Figure 2.

36. BS 5400 Part 9.1 Clause 10.1.3(d) states that the design of elastomeric bearings should be such that *"either they do not slip under the applied forces when checked in accordance with 10.11 or they are mechanically fixed to the structure above and below."* Clause 10.11 contains the formulae for determining whether or not friction is adequate. The formulae in Clause 10.11 are independent of the coefficient of friction of

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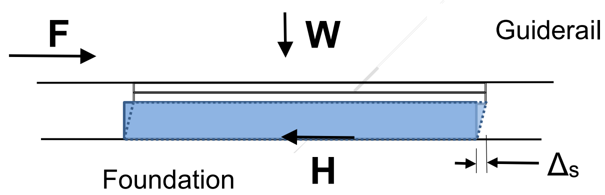
[2] Superelevation is where there is a slope from one side to the other and is employed on transport infrastructure projects to aid drainage and to ease vehicles traversing a curve in the longitudinal alignment of the project.

[3] Reaction force is defined as the force exerted on a structure when it rests on something – this is effectively Newton's Third Law which states, "For every action, there is an equal and opposite reaction." In this case, therefore, the reaction force is equivalent numerically to the load on a bearing.

bearing/shim interfaces etc., and we have calculated that the vertical load at a bearing requires (formula is $V > A_1(1+ b/l)$, where V is for self weight only, A_1 is the area of the bearing pad, and b & l are the dimensions of the pad) to be 205 kN. This shows therefore that there is inadequate friction according to BS 5400 Part 9.1.

37. Investigation H – Temperature Related Movements (see §130 below) shows that daily expansion/contraction of the guideway ladders is typically 2mm to 4mm and frequently greater than 2.5mm.

38. Notwithstanding the requirements of BS5400 Part 9.1, we have calculated that for an 'in-plane' ladder, with end bearing reactions of approximately 32kN (see paragraph 35 above), with coefficient of friction of 0.4, and with bearing pad shear stiffness of 5.4kN/mm (given by Ekspan in its bearing schedule), slippage of a bearing pad/shims can occur for thermal expansion/contraction of a guideway ladders only 2.37mm (see Figure 6 below). Given that thermal expansion/contraction is frequently greater than 2.5mm, the bearing design is flawed irrespective of the stiffness of the guideway superstructure because there is insufficient friction to retain the bearing pads in place even for an 'in-plane' guideway ladder undergoing thermal changes without trafficking of the guideway.



W = Minimum load on support = 32 kN

For bearing Shear Stiffness (Shs) = 5.4 kN/mm

F = Force required to distort bearing by $\Delta_s = 5.4 \times \Delta_s$

μ = Coefficient of friction = 0.4

H = Available frictional restraint = $W \times \mu = 32 \times 0.4 = 12.8$ kN

To avoid slippage H must be greater than F

Therefore slippage will occur when $\Delta_s > 12.8 / 5.4 = 2.37$mm

Figure 6. Calculation for Slippage of Bearing Pad and/or Shims.

39. Acceptance of inadequate friction for fixity of the bearings and shims in our opinion constituted a failure to act with the reasonable skill and care to be expected from an ordinarily competent and experienced design engineer.

WHY BEARINGS AND SHIMS ARE COMING OUT – INVESTIGATIONS

Ladder Stiffness and the Design

40. DDG *Rev 6 states at Section 5.1:*

> *"The beams will be modelled by a simple line beam analysis taking into account lateral load, induced vertical load and torsion. Grillage analysis of the overall system using Superstress will be used to check the torsional effects applied to the overall 'ladder beam' structure."*

We acknowledge that the Works Information does not prescribe beam or ladder stiffness, nor indeed the form of the design and the method of construction. However, in our view, the Works Information does require a stable design where the performances of the superstructure and the substructure meet the needs of each other. In this respect, the provisions of BS 5400 are relevant. Part 1 refers to the objective of BS 5400 as follows:

> *"The aim of BS 5400 is the achievement of acceptable levels of probability in order that the structure being designed will not become unfit for the use for which it is required, i.e. that it will not reach limit state during its design life. It specifies certain design requirements and a coherent set of partial safety factors for bridges in the UK), which combine to provide what is considered to be an acceptably low probability of attaining the limit states given in Clause **3**.*
>
> *It has been assumed in the drafting of this British Standard that the executions of its provisions will be entrusted to appropriately qualified and experienced people."*

Furthermore, Clause 3.4 of BS 5400 Part 1 states:

> *"The configuration of the structure and the interaction between the structural members should be such as to ensure a robust and stable design. The structure should be designed to support loads caused by normal function, but there should be a reasonable probability that it will not collapse or suffer disproportionate damage under the effects of misuse or accident."*

41. The design therefore needed to be stable and needed to work.

42. We have neither found nor been provided with the design calculations to see how or what torsional effects were determined. We understand that these have never been provided to Atkins despite its requests to BAMN.

43. DDG Rev 6 also states at Section 5.3:

> *"Concrete section properties will be calculated in accordance with BS 5400 part 4 clause 4.4.2.1(c), i.e. net transformed sections."*

44. BS 5400 Part 4, Clause 4.4.2.1 states:

> *"<u>General</u>. Elastic methods of analysis should be used to determine internal forces and deformations. The flexural stiffness constants (second moment of area) for sections of discrete members or unit widths of slab elements may be based on any of the following.*

a) <u>Concrete section</u>. The entire member cross section, ignoring the presence of reinforcement.

b) <u>Gross transformed section</u>. The entire member cross section including the reinforcement, transformed on the basis of modular ratio.

c) <u>Net transformed section</u>. The area of the cross section which is in compression together with the tensile reinforcement, transformed on the basis of modular ratio."

45. The stiffness characteristics of the ladder assemblies including the 'rigidity' of the spacer to guideway connection was in the control of the designer. The implications of assumed uncracked section (i.e. using the entire member cross section) versus gross transformed section versus net transformed section (BS5400 Part 4 Clause 4.4.2.1) should have been considered.

46. We believe it was acceptable for the <u>analysis</u> of the structure to be based on a 'net transformed section'. However, we believe that, given the superstructure and the foundation design were interdependent, the sensitivity and implications of the alternative approaches in §44 above should have been examined. If it then proved necessary for the 'actual' stiffness, both longitudinally and laterally, to be confirmed, testing a guideway ladder should have been considered. Compatibility of actual superstructure stiffness with behaviour of the foundations would then have been achieved in the design.

47. The problem on the busway is that the ladder is actually behaving more stiffly both longitudinally and laterally than assumed by the designer. As a result, it cannot accommodate, without rocking or see-sawing, the design-specified differential movement between foundations or the design specified lateral tilt of any single foundation. The design is in our opinion flawed in this respect.

Investigation A – Stiffness Characterisation

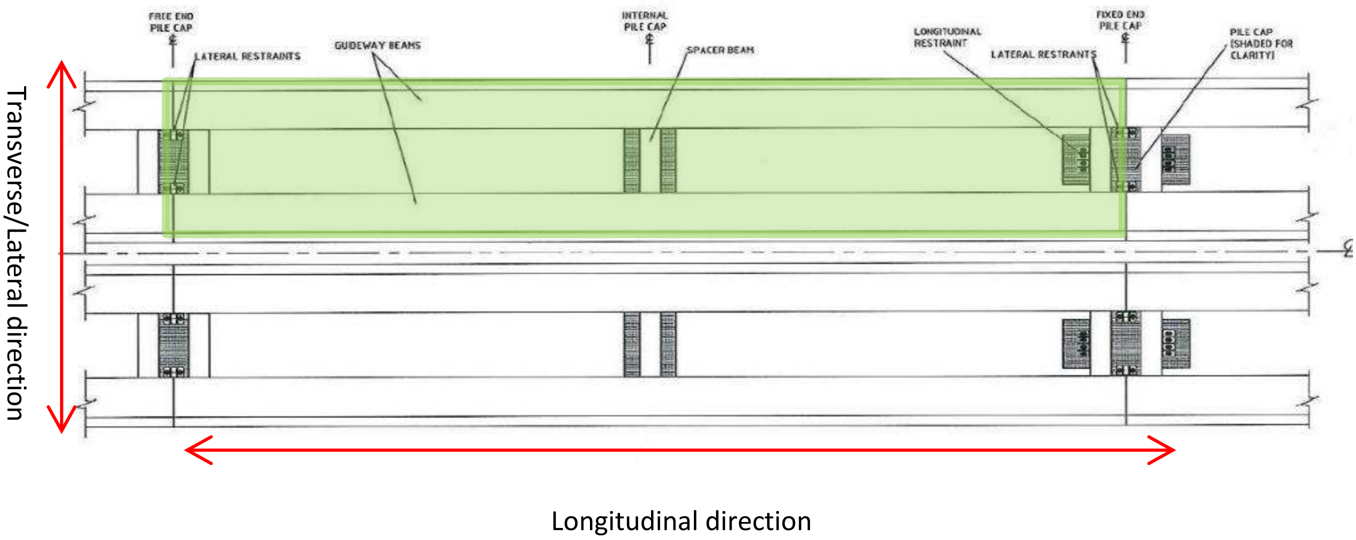


Figure 7. Indicative Plan on Guideway 'Ladders' (Single assembly shown highlighted green).

48. Analysis of the test results from Investigation A has indicated that the guideway ladders are behaving in a much more rigid (stiff) way than was thought previously, both longitudinally and transversely. Previously

we had assumed that the guiderails would be performing as a cracked concrete element, in response to settlement or heave or loadings on the guiderail e.g. bus loadings. This was on the basis of BAMN's design statement that the guiderails could deform by up to 25mm longitudinally and 10mm laterally to accommodate foundation settlement.

49. The surface cracking, visible at the top surface of many of the guideway beams, appeared to support this approach. We therefore previously adopted:

(i) flexural stiffness properties for the guiderails that reflects a cracked beam element. That is, areas of concrete assumed to be in tension were ignored and replaced with a factored value of the reinforcement area within this tension zone. We then calculated the flexural stiffness using the remaining area of concrete, assumed to be in compression, and this factored area of reinforcement together with the geometric relationship between them. This is referred to as a *"net transformed section"* in BS 5400-4:1990, clause 4.4.2.1 (c). The longitudinal stiffness now assessed from the measured data in the additional investigations indicates the guiderails approximate to the flexural characteristics of an uncracked element. Thus our current analyses utilise the full cross sectional area of the concrete, ignoring the reinforcement, to obtain a value for the flexural stiffness. This is referred to as a *"concrete section"* in BS 5400-4:1990, clause 4.4.2.1 (a).

(ii) a reduced modulus of elasticity[4] to consider the difference in the effects of the long term (permanent) and short term (bus) load effects on the guideway. Table 3 in BS 5400-4: 1990, provides values of the modulus of elasticity (E_c) of concrete under short term loading for various concrete strengths. It is then normal to allow half the tabulated value when considering long term loading to take what engineers refer to as creep into consideration. In adopting this approach, we used a modulus of $\frac{3}{4}E_c$ (equivalent to an average value $[(E_c + \frac{1}{2}E_c)/2)]$. The longitudinal stiffness now measured indicates the guiderails approximate more towards the elasticity characteristics for short term loading. Thus our current analyses utilise the full modulus of elasticity for the concrete.

50. The guideway ladder is also stiff in a transverse direction so that it acts like a stiff plate such that the guiderails do not act as two independent elements of the guideway ladder. This means that any tilting/twisting of the guideway ladder and/or its associated foundation in a transverse direction has a marked effect on the vertical reactions (loads) at bearings, and in particular end (corner) bearings. Differential movement between foundations also has an effect on end bearing reactions.

51. A summary of the test results from Investigation A is enclosed in Appendix B.

Effect of 'In-Tolerance' Guideway Ladder Construction

52. By 'in-tolerance' we mean that, the guideway is constructed in accordance with the contract, within the specified tolerances in the Works Information. The tolerances are given at Clauses 21 and 22:

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4 Modulus of elasticity is defined as the ratio between a stress (i.e. force per unit area) that acts to deform the body and the corresponding fractional deformation (i.e. strain) caused by the stress.

"21. The design levels of the guideway running surface shall be calculated from the design vertical alignment, superelevation and crossfalls. For the level of any point on the constructed surface the absolute variation from the design level shall be ± 6 mm for each guideway.

22. The relative step height between the two running strips on a guideway, measured in the plane of superelevation perpendicular to the design horizontal alignment, at points equidistant from the guideway centreline shall not exceed 2mm as shown on figure 22, both at construction and at handback after 10 years."

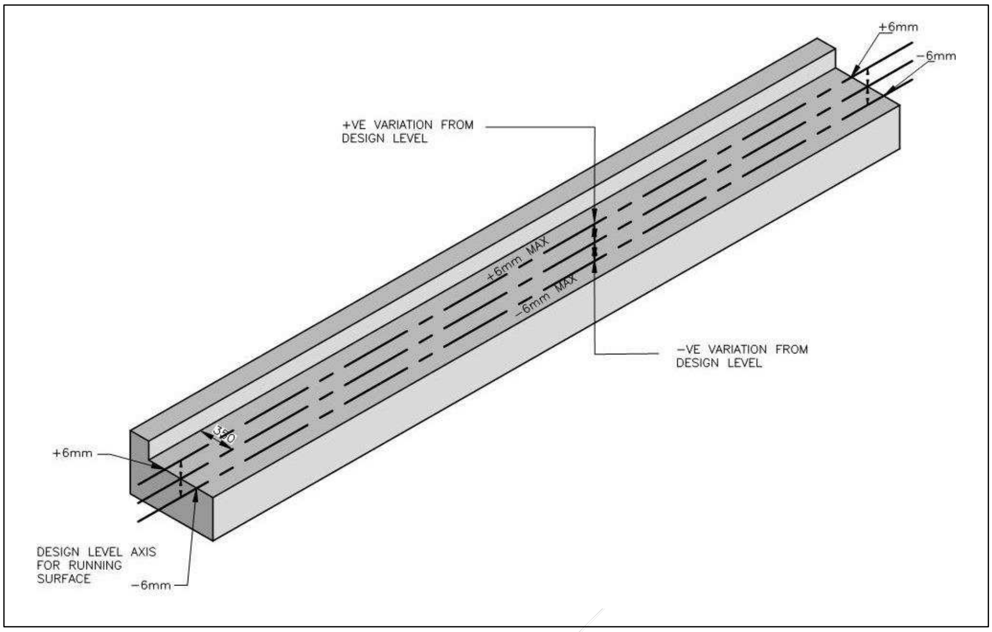

Figure 8. Permitted Variation from Design Level.

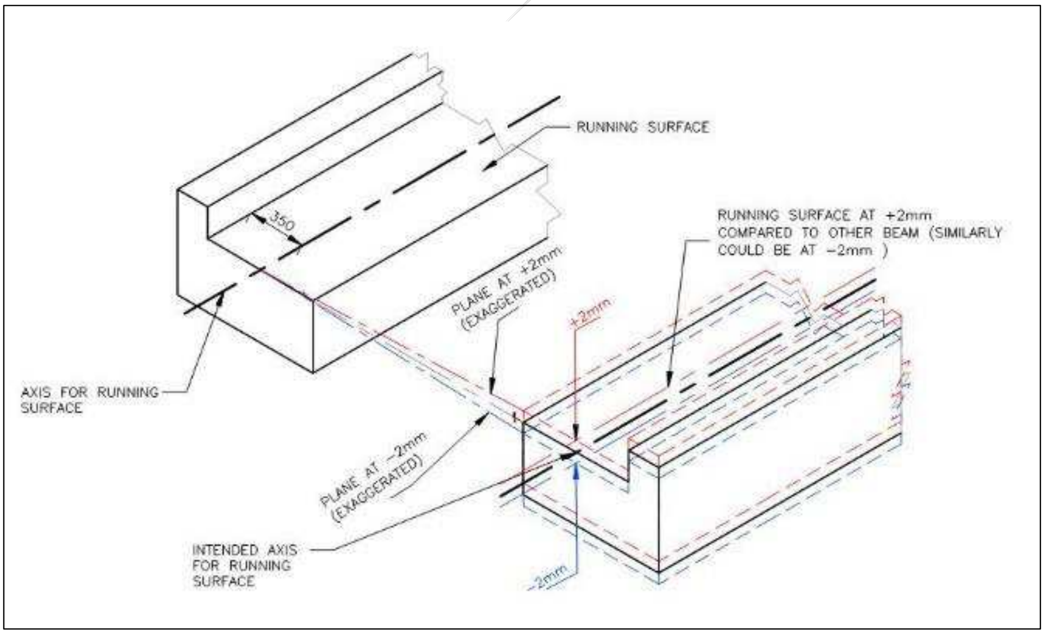

Figure 9. Permitted Variation in Level across Guiderails.

53. Clause 21 is illustrated at Figure 8 and Clause 22 is illustrated at Figure 9.

54. The Design Document for Guideway (DDG Rev 6) provides the same information on tolerances at Clause 4.2.8.

55. These permitted tolerances mean that the guideway can be constructed with non-straight beams and with a twist in the ladder assembly, i.e. the ladder is not then 'in-plane'.

56. We consider it possible, therefore, on the basis of permitted construction tolerances without even considering foundation movement, that shimming of the beams during construction could result in the guideway ladders being constructed out-of-plane with a slight twist built-in. The result of this could be, for construction in accordance with the contract, a reduced reaction at a bearing thereby increasing the risk of bearing and/or shim movement under smaller thermal expansion and contraction movements.

57. In the interpretative results from Investigation A enclosed in Appendix B, the figures in red denote negative numbers, i.e. downward displacements and reductions in load. As indicated above, a 2mm difference in level laterally (i.e. step height difference of running surfaces at points equidistant from guideway centre line) is permitted by the Works Information at paragraph 22 of Appendix 7/1. The results of the Investigation A tests show that a constructed 2mm difference in level laterally can reduce load on a bearing by around 15 kN (i.e. approximately 50%). A mere 4 to 5mm of lateral differential settlement is then sufficient to reduce bearing reactions to near zero, and thus frictional restraint also to near zero. This would mean that shims and/or bearings are then completely unrestrained and the guideway ladders are on the verge of rocking.

58. The Works Information (and the DDG Rev 6) requires a vertical tolerance from one side of the track running surface to the other of +/-2mm (i.e. laterally) and longitudinally to +/-6mm from the design alignment. On the basis of the findings detailed in §50 and §57 above, these tolerances alone can produce unacceptably low reactions at a corner of a guideway ladder because the guideway ladders are so stiff.

59. Further we have calculated that reactions can reduce to zero if diametrically opposite corners of a ladder are low by 2mm when the centre of the ladder is high by 6mm.

60. In essence, therefore, the guideway has not been designed to accommodate the permitted construction tolerances.

Effect of Foundation Movement

61. The Design Document for the Guideway (DDG) Rev 6 (which is not part of the Works Information) was part of the design prepared by BAMN and accepted by the Project Manager. Thus work not in accordance DDG rev 6, is a Defect. This document states at Clause 4.2.5.8 that the design of the guideway will allow for a maximum differential settlement of 25mm between adjacent supports in the longitudinal direction. It also states that the design of the guideway will allow for a maximum transverse differential settlement across foundation bases of 10mm and that the 10mm transverse differential settlement is not in addition to the 25mm longitudinal differential settlement.

62. For the guideway ladders in their present form, the guideway is behaving too stiffly to accommodate, without bearing pads and/or shims coming out or without rocking or see-sawing of the ladders, the longitudinal and

transverse differential settlement figures of 25mm and 10mm respectively stated in the design document DDG Rev 6.

63. Furthermore, the Maintenance Manual BAM137A/CGB/MM/09 Rev 6 states, *"The design allows for a maximum adjustment due to heave of 10mm. That is, the shims have been initially set at a thickness of at least 10mm."* Up to 10mm of foundation heave was therefore supposed to be allowed for in the provision of the shims, as the design stipulated (Drg No CGB/GD/B/010Z) that the shims would be initially set at 10mm. These shims could be removed. The design further allowed for up to 35mm of shims to be placed and thus, if 10mm of shims had been installed, the maximum possible upward adjustment of the guideway to accommodate settlement of the foundation would be 25mm.

64. Our analysis shows that movements below the above figures (i.e. 25mm longitudinally and 10mm transversely) can give rise to rocking (side to side) or see-sawing (end to end) of the ladders. Such rocking and see-sawing has been observed in the operation of the guideway. Assessment of the results from Investigation A shows that the guideway ladder is so stiff transversely that even for an in-plane ladder a mere 1mm of differential settlement between end bearings (side to side) for a given support will cause a significant reduction (approximately 25%) in the load reaction at that bearing. We assess therefore that a transverse differential settlement of only 4mm is sufficient to reduce an end bearing reaction to approaching zero, meaning that shims and/or bearings are completely unrestrained and the guideway ladders are on the verge of rocking.

65. Similarly, again assuming there is no out-of-planeness of the constructed ladder the stiffness in the longitudinal direction is such that, on average, around 12mm settlement of four end bearings (i.e. at both ends of a guideway ladder) relative to centre bearings could cause reactions at each of the end bearings to approach zero as a bus travels over the length of the guideway. Consequently the longitudinal differential settlement between both ends of a guideway ladder relative to the central support of about 12mm would also mean that shims and/or bearings are completely unrestrained and the guideway ladders are on the verge of see-sawing.

66. It is evident therefore that differential movement between adjacent foundations and lateral tilting of foundations can severely further affect the vertical reaction at a support/bearing and reduction of this reaction will further increase the likelihood of shims and/or elastomeric pads coming out.

67. An unknown element is the effect of any future foundation movement on the guideway ladders. It is possible this would increase crack depths in the concrete thereby reducing the stiffness of the guideway. We have not considered this aspect.

Effect of Low Coefficient of Friction of Shims and Elastomeric Pads

Investigation G – Coefficient of Friction Tests on Shims and Elastomeric Pads

68. The design intent that friction is adequate to retain the bearing pads in place is given in Contract Specification 2100 and in DDG Rev 6 which refers to BS5400 Part 9 for the design of the bearings – see §33 above. The design intent is also described in the Maintenance Manual BAM137A/CGB/MM/09 Rev 6 at Section 3.4.1 which indicates that the bearing pads are not fixed to the guiderail or foundation and that

friction is adequate to prevent relative movement. Because the bearings and shims are moving and slipping out, we decided that it would be appropriate to ascertain the coefficient of friction between the various interfaces (shim to concrete, shim to shim, shim to bearing pad, and bearing pad to concrete). If the coefficients of friction are low then it would be reasonable to conclude that these are further exacerbating reasons for the shim and bearing pad displacements that have been observed.

69. The purpose therefore of Investigation G was to test the frictional resistance of shims and bearing pads. The results are summarized thus:

Total Shim Tests	Condition	No. Tests	Peak Coefficient of Friction		Res. Coefficient of Friction	
			Range	Ave.	Range	Ave.
			Individual Stage		Individual Stage	
New Shim v New Shim	Dry	3	0.44-0.64	**0.55**	0.30-0.38	0.33
Used Shim v Used Shim	Dry	3	0.26-0.45	**0.36**	0.15-0.28	0.22
Used Shim v Used Shim	Wet	3	0.34-0.51	**0.40**	0.21-0.31	0.26
Used Shim v Bearing	Dry	3	0.37-0.54	**0.43**	0.28-0.51	0.36
Used Shim v Bearing	Wet	3	0.32-0.41	**0.36**	0.27-0.44	0.34
Used Shim v Concrete Beam	Dry	3	0.43-0.53	**0.48**	0.20-0.34	0.27
Used Shim v Concrete Beam	Wet	3	0.40-0.60	**0.46**	0.19-0.39	0.28
Bearing v Concrete Pad	Dry	3	0.27-0.38	**0.31**	0.26-0.30	0.28
Bearing v Concrete Pad	Wet	3	0.27-0.37	**0.32**	0.25-0.34	0.29
		27				

Figure 10. Investigation G coefficient of friction test results.

70. Tests were also carried out on both original (used) and replacement (new) shim materials because we noted they were different in appearance. The tests showed that the used and new shim materials have different frictional characteristics. Our enquiries have indicated that they are of different manufacture. The results of the used shims are of greater relevance to shim stability since these constitute the majority of the constructed guideway.

71. There is an assumed requirement for the bearing pads to also have a coefficient of friction of 0.4 in Contract Specification 2100 (see footnote to the Bearing Schedule), though this was not referred to on the drawings. Commensurate with this, we have found no design requirement for the elastomeric pads to be fixed to the concrete foundations. We note, however, that Ekspan (the bearing pad manufacturer) had stated in its bearing schedule the need to fix the bearing pads to the foundations but this was not specified in the design of the guideway.

72. Investigation G has indicated that the coefficient of friction of the shims is variable. The used shim surfaces and bearing pads have coefficients of friction that vary substantially and many of these are less than 0.4. Minimum values for the coefficient of friction (peak coefficient of friction columns in Figure 10 above) of used shims vary from 0.26 to 0.37. Significantly, the coefficient of friction between elastomeric pads and concrete are generally less than shim to concrete and shim to shim i.e. there is less restraint to the bearing moving under a load than the shims. In our view, this in part explains why pads have often come out, leaving the shims behind – see Figure 11 below. There are several interfaces at a bearing (pad to concrete, pad to shim, shim to shim, shim to concrete. Consequently, whether pads or shims move out depends on the respective coefficient of friction at each interface.

73. Our analysis shows that even a coefficient of friction as high as 0.35 is significant in contributing to loss of bearings and/or shims and thus the recorded coefficients of friction show a significant contribution to the losses.

Figure 11. Bearing pad has 'walked out' from beneath the shims.

74. What is clear from Investigation G is that the risk of bearings and/or shims moving out is <u>further</u> increased because of lower coefficients of friction that are often less than 0.4.

Summary

75. The design is inadequate in the restraint of shims and elastomeric pads. Even for an 'in-plane' guideway ladder, the restraint inadequate in resisting movement caused by thermal expansion and contraction of the guideway ladders. The risk of the shims and elastomeric pads coming out is further exacerbated by each of the following effects:

(i) Permitted construction tolerances;

(ii) Foundation movement; and

(iii) Low coefficients of friction.

76. This is the fundamental defect in the design and construction of the Guideway. In our opinion, any remedial scheme needs to address the stability of shims and bearings.

FOUNDATION MOVEMENTS AND SHIM/BEARING PAD MOVEMENTS EVIDENCED BY INVESTIGATIONS B, C, D, F & J

<u>Investigation B1 – Boroscope Bearing Surveys</u>

77. Investigation B1 photographs show, in our judgement, that 11 bearings out of 56 (20%) exhibit shim movement relative to bearing pads between the photographs of January 2014 and December 2015. It is not possible to determine from the photographs whether there is ongoing movement of the pads. No shims or pads have become completely displaced, though one bearing shows shims displaced by an estimated 150mm. Appendix C summarises our interpretation of the shim movements relative to the bearing pads.

Investigation B2 – Level Surveys at Longstanton

78. Investigation B2 shows there is twist in some of the guideway ladders that may be linked to shim movement.

79. Our calculations using the foundation survey information indicates that 7 of the 14 foundation pad top surfaces are out of the horizontal plane by over 2mm the permitted tolerance for the overlying guiderail in DDG Rev 6.

Investigation C – Walkover Survey

80. Investigation C shows that some 3.9% of joints have vertical steps that exceed 2.0mm (which is greater than the permitted construction and handback tolerance of 1mm in DDG Rev 6). In our view vertical steps are the result of bearing/shim loss and/or possible tilting of foundations about a transverse axis.

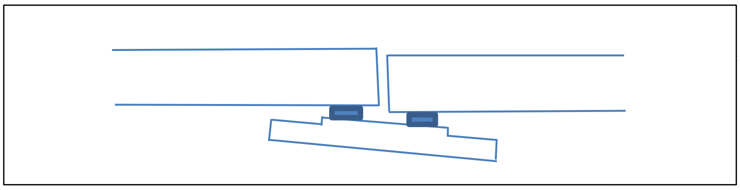

Figure 12. Diagram (exaggerated for clarity) **showing how tilting of foundation can result in a step at a joint.**

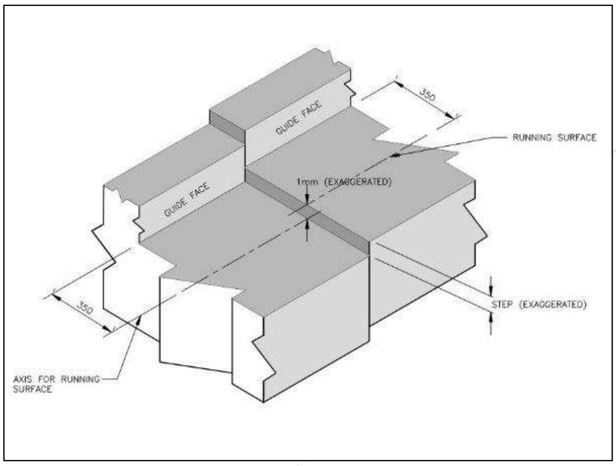

Figure 13. Vertical step tolerance at joint.

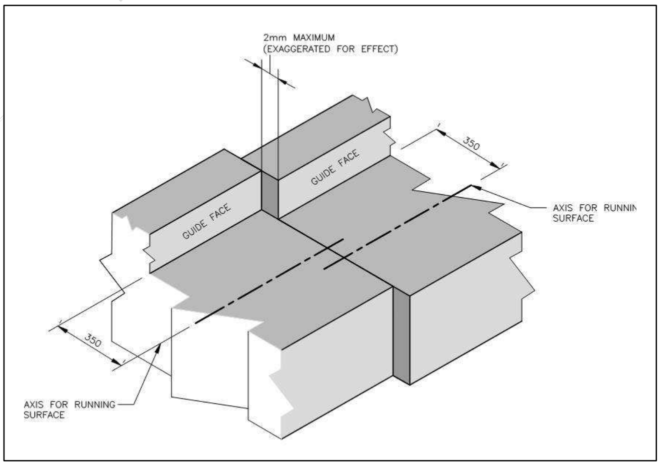

Figure 14. Horizontal step tolerance at guide face.

81. Investigation C records, inter alia, vertical and horizontal steps at joints. Figures 13 and 14 above show the limits of these steps required by the Works Information. We include in Appendix D, summaries prepared by Atkins of the extent of vertical and horizontal joint displacement before the investigations, surveyed from September to November 2015 and since Investigation C (based on a survey by Atkins on 16 May 2016). . Atkins has carried out an assessment of the Investigation results and compared these with the step dimensions in Defect Notice 287 and 288. This led Atkins to carry out a re-survey in May 2016 to resolve certain anomalies in the results. This showed that in some 13 instances the Defect Notice dimensions were incorrect and that in several locations the steps had increased in height. Atkins has reported (see letter to BAMN dated 26 July 2016 included in Appendix D) that there are 343 instances (i.e. 6.1%) of vertical steps at joints greater than 2mm.

Investigation D – Level Surveys at Various Locations (Beam Ends)

82. Investigation D shows that, where there are vertical steps, many of these are accompanied by out-of-plane[5] guideway ladders. We believe it reasonable to conclude that in such situations, foundation movements, which can result in reduced bearing reactions, are contributing to the bearings and/or shims coming out.

83. Investigation D shows that 812 out of the 942 (about 86%) guideway ladders surveyed are out of plane by amounts that exceed the contractual tolerances and handback tolerances as stated in the Works Information, i.e. paragraphs 21 and 22 of Appendix 7/1 (see §81 above). These tolerances are also referred to in the DDG Rev 6. In addition, there are some 762 guideway ladders (about 81%) containing a twist or longitudinal out-of-planeness that in our opinion is unacceptable (based on reaction reduction discussed in §57 and §65 above) as regards the effect on bearing/shim stability, and has given, or is likely to give, rise to increased bearing/shim loss in the future. Furthermore, from our analysis of the stiffness of the guideway ladders, there are 547 guideway ladders (about 58%) with distortions greater than either 4mm laterally or 24mm (i.e. equivalent to 12mm at both ends) longitudinally. At these locations, there is, in our view, likely to be approaching zero load on the shims and bearing pad(s) resulting in negligible friction to retain them in place, and thereby exacerbating the risk of bearing pad and/or shim loss with thermal expansion/contraction movements 'walking' them out and/or the loading/unloading events from vehicle trafficking vibrating them out.

84. If the levels from Investigation D denoting out-of-plane guideway ladders were to be representative of the whole guideway (which we consider to be likely), this would suggest that at least one third of the bearings over 80% of the guideway could be at increased risk of coming out on the basis that two diametrically opposed bearings out of the six per ladder are likely to be affected. However, as indicated above at §32 to §36, even for an 'in-plane' guideway ladder, there is a risk of the end bearings coming out which would equate to two thirds of the guideway supports (bearing pads and/or shims).

Investigation F1 – Boroscope Bearing Surveys

85. Investigation F1 photographs are at several locations where vertical steps at joints have been recorded in the Investigation C survey. It appears that many of these are associated with where bearing pads and/or shims have come out.

86. Appendix E summarises the observations we have made from the 209 beam support boroscope survey photographs. We have taken the reasonable assumption (in the absence of a baseline survey at construction) that the bearings and shims were constructed by BAMN in a neat stack and not in a disorderly and irregular stack. Examination of the photographs show that in some locations shim and bearing movements are relative to each other whilst in other locations it appears that the bearings are moving out or have moved out entirely and sometimes with little apparent movement of the shims.

[5] 'Out-of-plane' means that there is a change of gradient longitudinally and/or transversely along the length of the ladder.

Photograph observations	Number of supports
Shim thickness estimate > 35mm	9
Shim thickness estimate < 10mm	65
Shim or bearing movement visible	56

Table 1. Summary of Investigation F1 boroscope survey.

87. Table 2 summarises the number of occasions where the shim thicknesses are greater than and less than provided for by the accepted design. It also indicates the number of investigation F locations where significant shim and/or bearing movement is evident – in our view this comprises 27% of the bearings photographed.

88. Shim estimates greater than 35mm thickness relate to chainages 17226, 17781 and 17896 only.

89. Shim estimates less than 10mm thickness include 10 locations where shims were not visible and could relate to displaced bearing or shims.

Investigation F2 – Level Surveys at Various Locations

90. Investigation F2 (level survey) was undertaken between 14 and 17 December 2015. Table 2 summarises the results of the level survey in terms foundations and guiderails of out of horizontal plane and relationships with shim or bearing displacement.

Observations	Number of support locations	Number of shims with significant displacements	Number of supports including foundation levels out of plane > 2mm in same direction
No. of guiderail levels > 2mm out of plane away from the guideway centreline	42	26	11
No. of guiderail levels > 2mm out of plane toward the guideway centreline	34	12	15
No. of foundation levels > 2mm out of plane below guiderail centres away from the guideway centreline	20	10	–
No. of foundation levels > 2mm out of plane below guiderail centres toward the guideway centreline	58	26	–

Table 2. Summary of Investigation F2 level survey.

91. Figure 15 below presents diagrams to explain the descriptions in Table 2 above.

92. Of the 26 supports where the guiderails and foundations are out of plane in the same direction with vertical differences of greater than 2mm, 10 of the supports are adjacent to each other on the same foundation which relates to movement of five foundations.

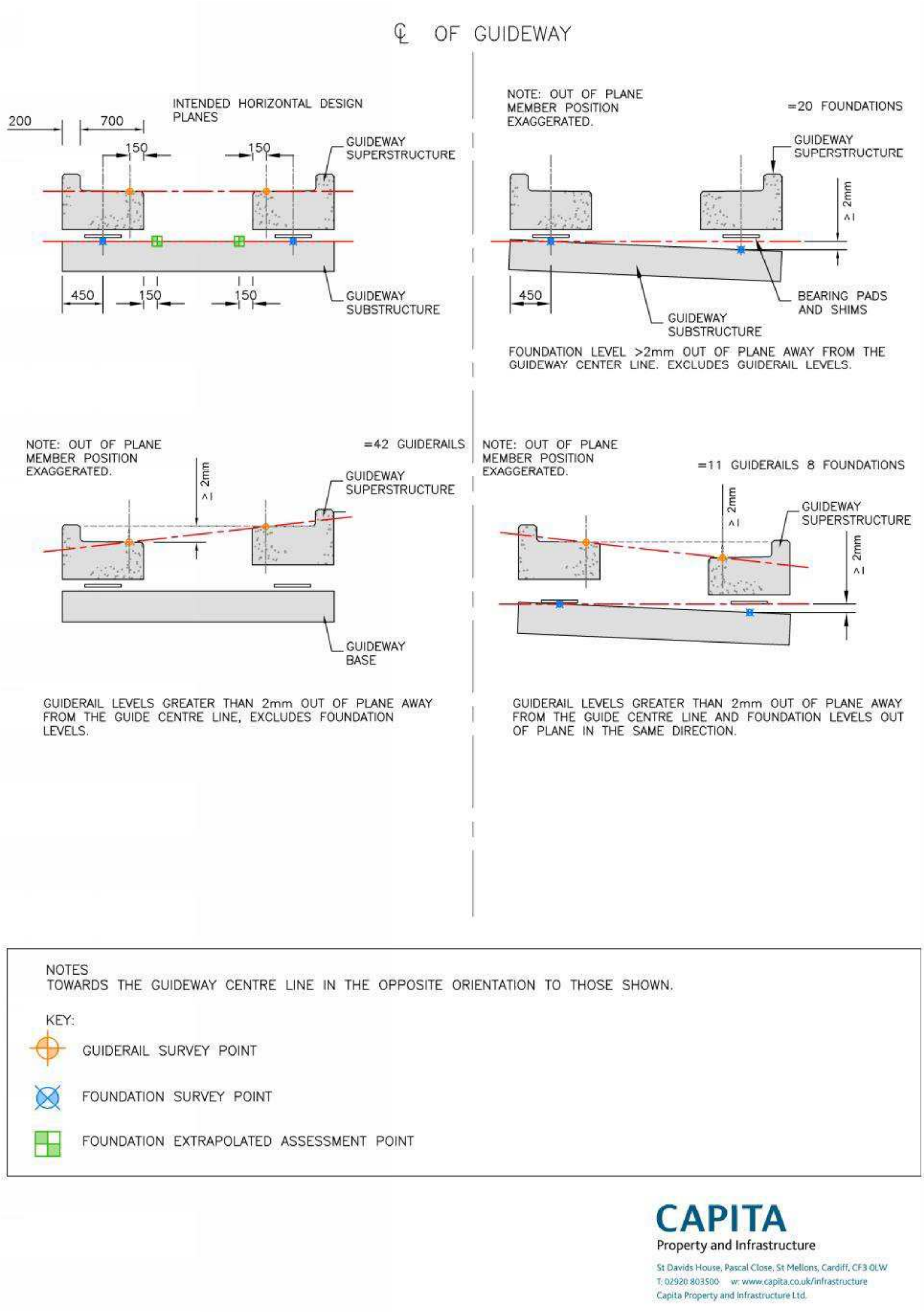

Figure 15. Diagrams to accompany Table 3.

93. Of the 56 bearing and shim displacements observed, 38 relate to the northern section and 18 relate to the southern section. On the northern section 29 are located where guiderails are more than 2mm out-of-plane. It appears that out-of-planeness contributes to bearing/shim loss but is not the only mechanism. Bearings/shims can displace and come out as a result of thermal expansion/contraction alone because there is insufficient friction to retain them in place even for 'in-plane' guideway ladders. We describe the mechanism(s) for this at §107 to §111 below.

94. A summary of Investigation F is enclosed in Appendix E, with a description of the photographed Defects including where shims and bearing pads have come out.

Investigation J – Foundation Level Monitoring at Various Locations

95. Investigation J was proposed by BAMN to identify vertical height changes over time due to changes in seasonal weather conditions. There have been a number of issues relating to the reliability of the datums installed by the survey contractor as a limited number have been shown to have moved relative to stable datums installed at Bridge Road Bridge. The survey contractor has provided ongoing revisions to the data supplied such that the information recorded within this advice note may not be the final agreed data set.

96. Capita proposed additional locations on the basis of those assessed with the potential to indicate relative movement related to tree influence on the underlying clay soils

97. A total of 1108 guiderail support level points relating to 93 end-of-guiderail and 91 mid-span chainages were selected to be monitored monthly. Based on the lateral out-of-planeness tolerances identified from Investigation A (§57), a change of 2mm was selected by us to estimate the number of bearings/shims locations at risk.

98. Table 4 and Table 5 below summarise the results of the monitoring.

	Total No. of adjacent guiderail support locations levelled	No. of levels with > 1mm out-of-planeness away from guideway centreline	No. of levels with > 1mm vertical out-of-planeness toward guideway centreline	Total No. of guiderail points levelled	No. of levels with > 1mm heave difference to previous month	No. of levels with > 1mm settlement difference to previous month	No. of levels with > 1mm heave difference to October 2015	No. of levels with > 1mm settlement difference to October 2015
Oct 2015	558	165	291	1116	N/A	N/A	N/A	N/A
Nov 2015	554	160	295	1108	32	154	32	154
Dec 2015	554	160	294	1108	61	157	33	298
Jan 2016	554	155	294	1108	104	84	49	377
Feb 2016	554	154	299	1108	100	161	55	479
Apr 2016*	554	164	295	1108	376	177	222	420
May 2016	554	157	299	1108	269	265	140	375
June 2016	554	158	298	1108	163	55	173	339
July 2016	554	156	295	1108	75	94	155	351
Aug 2016	554	161	290	1108	204	137	260	361

* We currently believe this to have been surveyed inconsistently and are awaiting a reply by the survey contractor

Table 4. Summary of Investigation J monthly level monitoring showing +/- 1mm vertical variations.

	Total No. of adjacent guiderail support locations levelled	No. of levels with > 2mm vertical out-of-planeness away from guideway	No. of levels with > 2mm vertical out-of-planeness toward guideway centreline	Total No. of guiderail points levelled	No. of levels with > 2mm heave difference to previous month	No. of levels with > 2mm settlement difference to previous month	No. of levels with > 2mm heave difference to October 2015	No. of levels with > 2mm settlement difference to October 2015
Oct 2015	558	117	248	1116	N/A	N/A	N/A	N/A
Nov 2015	554	116	242	1108	9	40	9	40
Dec 2015	554	112	244	1108	15	32	18	61
Jan 2016	554	110	246	1108	21	0	22	74
Feb 2016	554	108	245	1108	37	62	42	177
Apr 2016*	554	119	247	1108	202	66	74	252
May 2016	554	112	247	1108	130	144	70	172
Jun 2016	554	114	246	1108	32	16	90	169
July 2016	554	115	248	1108	25	19	86	196
Aug 2016	554	121	246	1108	99	79	119	173

***** updated August 2016

Table 5. Summary of Investigation J monthly level monitoring showing +/- 2mm vertical variations.

99. There may still be some inconsistencies in the data set, relating to adjustments made as the surveyors when they changed to a new datum. This being reviewed by the survey contractor.

100. Defect correction works were reported to be carried out on displaced bearings and shims in January 2016 between chainages 17531 and 17586 on both guideways. The level surveys show an increase in level of the monitoring points on the guideway of between 0.5 and 10.4mm on the Cambridge-bound guideway but no such increase in the St. Ives-bound survey data. The result of Defect correction work is that 16 survey locations show an increase in level to the previous month's level greater than 1mm and 13 survey locations show an increase greater than 2mm.

101. The Investigation J data indicates that there is a significant number of vertical guiderail movements of greater than 1mm each month.

102. A significant number of guiderail ends that were levelled are potentially out of a horizontal plane (over 80% > 1mm and over 60% > 2mm).

103. Inspection of the guiderail surveys between October 2015 and June 2016 indicates that vertical difference between adjacent beams ends (out-of-planeness) has increased between beams by greater than 1mm at up to 92 survey locations.

104. The implications of monthly vertical displacements is that to keep the guideway in plane the guiderail supports would need to be maintained by adding or removing shims on a monthly basis. This is an unacceptable level of maintenance for a design condition particularly when one takes into account a requirement to avoid health and safety risks related to maintenance.

Conclusions from Investigation Evidence

105. The results of the investigations confirm to us that the contractual requirements and the design intent (see §33 & §34 above) have not been realised. Analysis of the investigation results confirm that there is insufficient friction to hold the bearings in place. This is primarily due to the lightweight form of construction that results in inadequate friction at the end bearings of each guideway ladder. The vertical load is far below that required by BS5400 Part 9.1. In addition, the inherent stiffness of the guideway ladders means that they have an inability to deform to accommodate the differential vertical movement (longitudinally and transversely) of the foundations which have occurred or might occur in future. This stiffness means that if there is any significant differential transverse vertical movement, even a mere 2mm, there is or will be a very substantial variation in load on the bearings. As friction is a function of load, where the load is substantially reduced there will be even less friction to prevent the bearings moving. The investigations have shown a substantial number of the guideway ladders were either constructed, or have moved due to the inadequately designed and built shallow foundations, such that the ladders are twisted and loads reduced on the bearings. Notwithstanding this, we have calculated that bearing pad and/or shim movement can occur due to thermal movement alone even on ladders that display no out-of-planeness (see §32 to §37 above), and the probable mechanism for how the bearings/shims can displace and come out is shown diagrammatically in Appendix F.

106. Investigation J suggests that there is a potential for between 21 and 274 interventions on a monthly basis on the monitored section to maintain 2mm changes as identified from the level survey. Table 6 basically suggests the number of potential monthly interventions due to movements in supports of 2mm. We would not consider this a reasonable design condition.

HOW BEARINGS AND SHIMS ARE COMING OUT

107. We have given consideration to probable mechanisms that lie behind the 'walking out' of bearings and/or shims. One such mechanism is illustrated in the diagrams in Appendix F. The principle illustrated is that cyclic thermal expansion and contraction of the guideway beams can cause a bearing pad (or shim) to move in one direction only because of a lip forming in the bearing pad gives rise to resistance that is additional to friction alone – see Figure 16 below.

FILENAME	CHAINAGE	PHOTO REF	DATE	DIRECTION	DISPLACEMENT
Investigation F	6723	1	14/12/2015	St Ives	

Figure 16. Uneven compression of Elastomeric Bearing Pad.

108. This results in walking of the bearings. We are aware of research in the USA (papers in Texas and Florida dated October 1995 and March 2007 respectively) that investigate the walking out of bridge bearings due to the bearings being 'wedge shaped' in cross section, thereby providing greater resistance in one direction (up slope) than in the other direction (down slope). This is similar in principle to the CGB case which can give rise to greater resistance in one direction than in the other direction. Furthermore, the CGB bearing pads can become slightly wedge-shaped for various reasons – for example non-uniform load being applied, foundations not being parallel to the running surface due to construction details and tolerances (e.g. foundation installed horizontally whist the beam is installed at a gradient longitudinally), tilting of foundations, differential movement of foundations etc.

109. There is also advice available in the UK on the vulnerability of bearings to 'walk'. The Network Rail Standard, NR/L3/CIV/140/100GN, "Model Clauses for Civil Engineering Works, Section 100, Bearings" published 5 June 2010 for example. Within the General section, at 100.1, this states:

> *"Generally, elastomeric bearings should not be glued in place as this will inhibit their maintenance and removal. On the other hand, the vulnerability of the bearings to 'walk' (by creeping or ratcheting) shall be considered: this susceptibility can be exacerbated where (a) the top and bottom contact surfaces are not parallel (hence, these surfaces should be parallel with the bedding material) and, (b) the shear stiffness of the bearing is high compared to the frictional forces. Installing stainless steel keep plates on the bearing shelf around the base of the bearing will prevent it from 'walking'."*

110. In other instances, the displacement of the bearings/shims could be associated with rocking or vibration of the ladders resulting in the bearings being 'bounced' out, but we consider this to be a secondary mechanism.

111. There are yet further instances found during the investigations where <u>lateral</u> movement of pads has occurred. This may be caused by the effect of bearings becoming 'wedge shaped', through rotation / twisting of a guideway relative to the foundation, as referred to in the USA papers referred to in §107 above. An alternative cause may be differential settlement across a foundation where a tree might take out more water from the soil on the outside of the guideway than towards the centre resulting in increased settlement on the outside of the guideway.

112. Consequently, consideration has been be given to an appropriate remedial solution in relation to:

    (i) the foundations for limiting longitudinal and transverse differential movements, to restrict rocking or see-sawing of the guideway within the constraints of the original contractual design requirements;

    (ii) the guideway ladder, in restraining the bearings/shims. This is necessary to prevent loss of bearing pads/shims.

LACK OF LATERAL RESTRAINT

Theory – Calculation of possible capacity

113. Prior to development of the investigation proposals, we carried out calculations for the capacity of the lateral restraint brackets based on the manufacturer's literature for the plastic bolt sockets cast into the foundation concrete.

114. We calculated the ultimate capacity of the lateral restraint brackets to be in the order of 15 kN, and it was on this basis that we proposed on-site testing of the brackets as this was below the required capacity, 50kN.

Investigation C – Walkover Survey

115. Investigation C has shown that some 11% of joints have horizontal steps (or displacements) in the guide face that exceed 2 mm (which is the permitted construction and handback tolerance).

116. We include in Appendix D, summaries prepared by Atkins of the extent of horizontal joint displacement before the additional investigations; these were surveyed from September to November 2015 and since Investigation C (based on a survey by Atkins at 16th May 2016).. Atkins has carried out an assessment of the Investigation results and compared these with the horizontal step dimensions in Defect Notice 288. This led Atkins to carry out a re-survey in May 2016 to resolve certain anomalies in the results. Atkins has reported (see letter to BAMN dated 26 July 2016 included in Appendix D) that there are 504 instances (i.e.9%) of horizontal steps at joints in excess of 2mm.

Investigation E - Resistance of Lateral Restraint Brackets to Slip

117. Paragraph 4.4.1.17 of the Works Information includes the requirement, *"The guide kerb and attachments shall be designed to resist without displacement or deformation a sideways force of 50 kN applied at the top of the kerb"*. Investigation E has demonstrated that all 8 lateral restraint brackets (which similarly need to resist the 50kN applied force without displacement) tested have a restraint capacity much lower than the 50 kN requirement. Enclosed in Appendix G are graphs of the load versus displacement for each of the 8 tests. The failure load can be ascertained by examining these graphs; the failure load is when displacement of the brackets occurs. Our interpretation of the approximate capacities is as follows and is based on when movement of the brackets is detected in the tests, for which we have taken 0.1mm as the threshold:

Test No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
Estimated Failure Load	Inconclusive but less than 22 kN	4 kN	13 kN	10 kN	13 kN	8 kN	10 kN	9 kN

Table 7. Investigation E load capacity test interpretation.

118. BAM and the Design JV has suggested to us that WI 4.4.1.17 relates to displacement or deformation relative to the running surface. In our opinion, the clause is written so as to be generic, applying to all forms of construction. For the selected 'ladder construction', it effectively means that the guiderails themselves

must not move under a load of 50kN and therefore relates to the required strength of the restraint brackets and their fixings.

119. Our interpretation of the results is that the brackets have restraint capacity values of between 4kN and 13 kN with an average of 9.5 kN, very substantially below the required capacity. In our view this lack of required lateral restraint is responsible for the significant number of lateral steps. We believe the lateral loadings arise primarily from wind loading on the side of buses. In addition to wind, lurching of the buses due to uneven track levels could give rise to lateral forces on the guiderails.

120. We consider consequently that the horizontal steps or displacements are caused by inadequate lateral restraint.

121. We therefore conclude that any remedial scheme needs to address this inadequacy of lateral restraint.

LACK OF LONGITUDINAL RESTRAINT

Investigation C – Walkover Survey

122. Investigation C shows that the vast majority of the (so-called) fixed joints do not have abutting joints as designed. This means that the guideway is not properly restrained in the longitudinal direction. Where the joints are abutting, there have been instances of spalling, possibly due to rotation of the beams as a result of foundation movement:

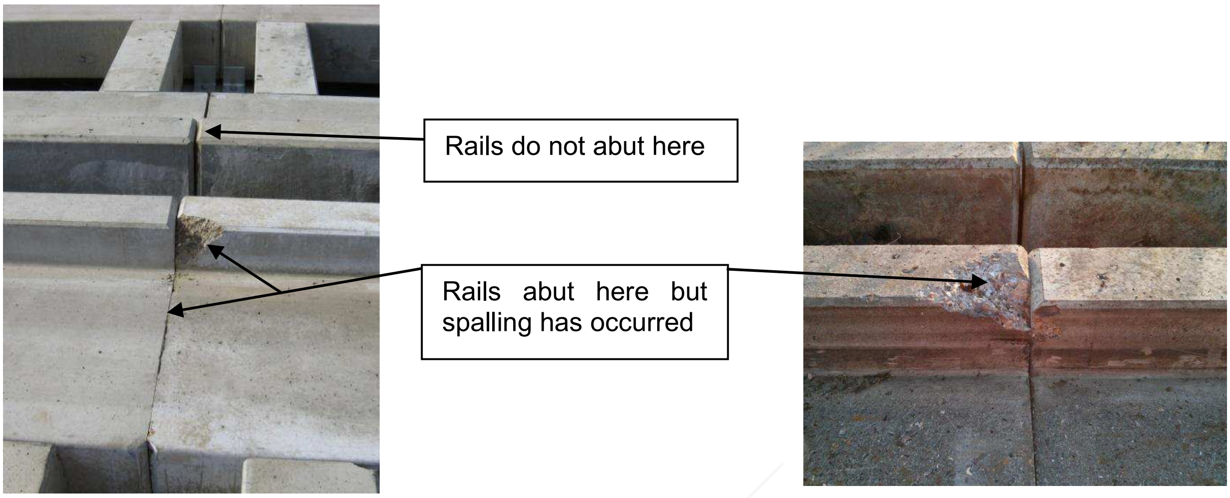

Figure 17. Photograph of guiderails not abutting, and spalling in locations where they do abut.

123. Notwithstanding the above, we have concerns about the stability of the guideway under the current operation of the guideway and normal bus traffic. Investigation C has also recorded many instances where the spacer beams have rotated which is also an indication of lack of longitudinal restraint. This indicates that the guideway ladders are not adequately restrained for normal busway operations (Investigation I was for an abnormal emergency braking circumstance using a fully-loaded double decker bus).

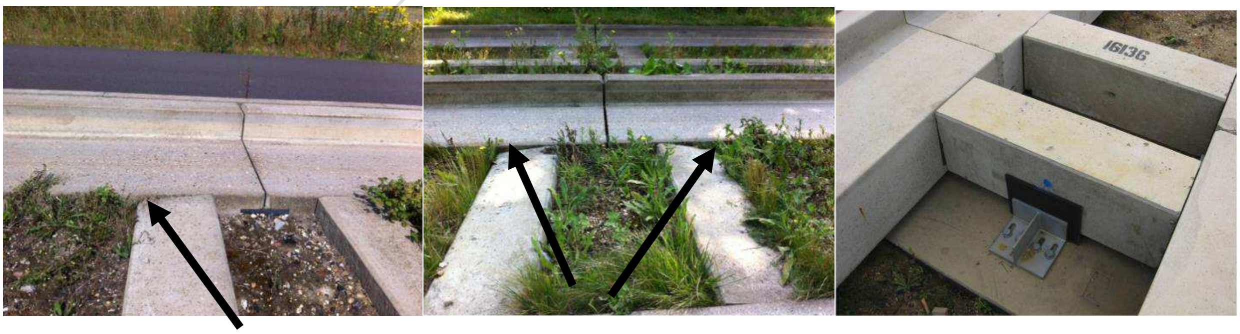

Figure 18. Photographs of rotated spacer beams. The marked sloping surfaces in the two photographs to the left were originally level with the guiderail as shown in the far right photograph.

124. Because the longitudinal restraint bracket rests against the spacer beam at the bottom (see photograph in Figure 18 above), there will be a rotating force (torque) applied to the spacer beam when horizontal forces arise where there is insufficient load on the bearings to resist these forces. This may be from thermal

movement alone. Given that there is insufficient friction at the bearings to resist these horizontal forces, the spacer beams are caused to rotate (torsion[6]) as can be seen in the photographs above.

Investigation I – Braking of a Fully Loaded Bus

125. Investigation I was carried out to measure longitudinal deformations under braking loads. The braking tests were initially carried out at two locations and gave unexpected results. Although there is a lack of longitudinal restraint by virtue of the gaps at the fixed ends, the guideway ladders in each case did not shift permanently under full braking of an ABS equipped, fully-loaded twin axle double decker bus from maximum speed (buses are limited to 56 mph on the guideway). The results indicate that the guideway ladders moved slightly under braking but only temporarily before reverting to their original position. We consider it is likely that there was sufficient frictional restraint caused by the loaded bus for the bearings/shims to resist sliding with the elastomeric bearings distorting under the longitudinal braking force and then reverting to the original state.

126. Braking tests were also carried out at a third location where foundations comprised screw piles and a reinforced concrete pile cap. The location chosen (chainage 12776 St Ives track) was where the ground conditions were assessed as the most adverse. Although movement was greater than with the pad foundations, transient movement recorded during full emergency braking was a maximum of about 1.4mm and residual movement was no more than around 0.1mm.

127. In the locations tested, the so-called fixed joints generally had open joints which meant that alternating guideway ladders were theoretically free to move (i.e. those ladders where the longitudinal restraint brackets were ahead of the moving bus). All the results indicate there was sufficient longitudinal restraint in the overall guideway ladder system for braking forces in those particular tests without relying on the brackets.Investigation I tested the worst traffic loading condition currently in operation on the busway, in terms of braking forces. However, it is possible in the future that triple action double decker buses could be used and these have a maximum weight of 24.4 tonnes compared with 18.0 tonnes for the twin axle bus used for Investigation I.

128. In our opinion, Investigation I did not comprehensively test the adequacy of the longitudinal restraint for several reasons:

(i) The tests were done with a fully loaded bus and the vertical load on the bearings was probably sufficient to make the bearings take the braking forces through friction and then in shear on the pads. The evidence is that during Investigation I the ladder moved and then moved back. We consider the ladder moved because of the gap at the fixed end;

(ii) Movement of the ladders is potentially possible under the travel of a lightly loaded bus, with less vertical load to generate friction to restrain the bearings and/or shims;

---

[6] Torsion is the twisting deformation caused when an object is subjected to a rotating force (torque).

(iii) the longitudinal brackets have been found to not always abut the spacer beams (see Figure 19 below) and, because of gaps between spacer beams and longitudinal restraint brackets, some of the longitudinal restraint brackets would not take a load;

(iv) although the longitudinal brackets were not tested, we estimate their capacity to be no more than four times the capacity determined for the lateral brackets (i.e. say around 40kN) since they have four bolts rather than the two bolts, of which only one was primarily tested under Investigation E, that retain the lateral brackets;

(v) the rotation of the spacer beam can occur if guiderails abut at fixed ends and longitudinal restraint brackets abut the spacer beams;

(vi) there may be friction from the backfilling etc. The adequacy of the longitudinal restraint should, however, ignore this contribution since it cannot be relied upon;

(vii) the load is in fact being taken, in part, by the bearings, contrary to the design intent; and

(viii) there would need to be factors of safety applied.

Figure 19. Photograph showing longitudinal bracket not abutting spacer beam.

129. In the light of these reasons, we recommend that either the remedial works are designed to accommodate the maximum loading conditions specified in the contract (using tied joints as referred to in our September 2014 report) or CCC agree to limit its operations to using only twin axle 18.0 tonne buses. For the purposes of this report, we have assumed the former.

NARROW GAPS AT FREE-END JOINTS

Investigation H – Temperature Related Movements

130. The design of joint widths appears to be based on the superstructure being in the open air rather than being buried, which is reasonable given that this is the approach of BS5400 and DMRB and test data for an alternative buried approach is not available. The results of Investigation H include monitoring during July 2016 in which high summer temperatures have been experienced. We have reviewed this data and found that since October 2015 (when movement readings at 15^{0}C were possible), there has been expansion of the guiderails of about 7.5mm at Locations 1 and 2. Given that the design provides for an expansion gap at the free end joints of 10mm at 15ºC, the monitoring suggests that the design is barely adequate as regards the provision for expansion of the guideway ladders.

131. The concern we had previously about reduced width of expansion joints (because there are gaps at most of the fixed ends) is therefore borne out given the commentary in §130 above. Given that we are proposing to introduce tied joints at the so-called fixed ends (see Drawing 4 in Appendix H) and to provide longitudinal restraint via the bearings, a 15mm total gap at 15°C at the free ends would be more appropriate in our opinion.

132. This investigation shows that day to night-time expansion/contraction cycle can be at least 1mm, frequently over 2.5mm, and has been recorded at as much as 4mm during July 2016. We consider that a typical range would be 2mm to 4mm. This would be accommodated by distortion of the elastomeric bearings except that in reality, there is insufficient reaction available to retain the bearings/shims in place when subjected to normal thermal expansion and contraction – see §37 below. Consequently, we propose to introduce bearing/shim restraint as shown on Drawings 1 to 3 in Appendix H.

133. Narrow free-end gaps, whilst being Defects in strict terms, are likely to be acceptable because gaps have arisen at so-called fixed ends which also provide for expansion. It is our view, on balance, that it is better to have fixed-end gaps than abutting joints because the latter gives rise to spalling in the surface of the guiderail upstands and in the running surface. This is because abutting guiderail ends restricts rotation caused by live load and/or differential foundation movement. Such spalling on the guiderail surface (see below) adversely affects ride quality.

SPALLING OF CONCRETE

134. We have commented on the spalling that has occurred at fixed joints recorded in Investigation C (see §122 above) which we believe results from an inability of the guiderails to freely rotate when subjected to foundation movement. We consider that this will adversely affect ride quality.

Investigation K – Survey of Spalling at Bottom of Guiderails (Behind Lateral Brackets)

135. Investigation K was carried out to assess concrete damage at the bottom of the joints in the guiderails at all locations where excavation had been carried out for Investigations B, E, F and I. There have been two investigations, one in February 2016 and one in August 2016. In the first survey, out of some 360 beam ends, 48 beam ends had 'significant' or 'severe' spalling (see §136 and §137137 below for defining of these terms), which in our opinion are likely to have given rise to exposure of reinforcement and/or require repair – this constitutes 13.4%. In the second survey, out of 401 beam ends, 54 beam ends had significant or severe spalling – this constitutes 13.5% had 'significant' or 'severe' spalling. In addition to these, some 12% of beam ends were found to have slight spalling which we consider to be sufficiently small to not warrant repair.

Figure 20. Spalling behind lateral restraint bracket

136. 'Significant' damage means that some form of resin or anti-carbonation coating can be applied by jacking up the beams – this only applies where the reinforcement is not exposed and where there is some (albeit small) concrete cover to the steel. We have assessed that, of the 13.5% significant or severe damage, some 7% (i.e. 53 No. out of 761) is 'significant'.

137. 'Severe' damage means that the reinforcement is likely to be exposed. The Contract Specification 1700 (i.e. Appendix 17/1) requires 50mm cover to the guideway beams for a Design Life of 40 years. If the cover to reinforcement is severely reduced and if reinforcement is likely to be exposed, it is liable to corrode and potentially reduce the life of the concrete guiderails. We therefore consider that such spalling constitutes a Defect and that repairs are needed to these areas which would involve lifting and inverting the guideway ladders. We have assessed that, of the 13.5% significant or severe damage, some 6.5% (i.e. 49 No. out of 761) is 'severe'.

138. We believe that the cause of the spalling is the localised pressure exerted by the lateral restraint brackets on the concrete at the lower corner of the guiderails. In particular, if the bracket is not perfectly aligned against the concrete of the guiderail, there would be a point load contact which would then cause the spalling of the concrete.

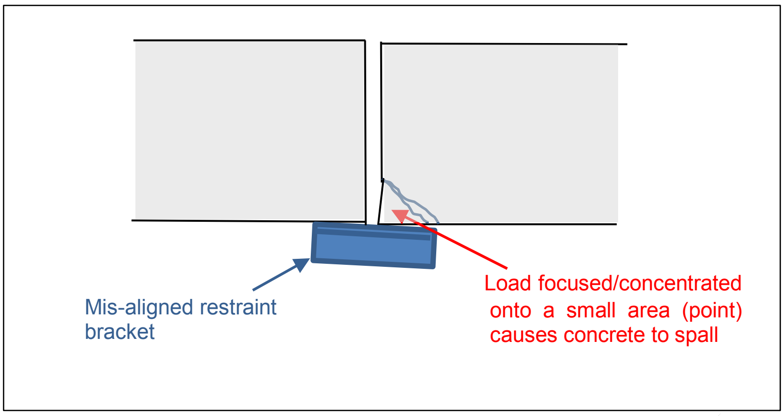

Figure 21. Diagram (Sectional Plan View) showing how spalling can occur

139. This has implications for the remainder of the guideway which has not been investigated. It is relevant that 13.4% of 360 surveyed beam ends in February and 13.5% of 401 surveyed beam ends in August 2016 (randomly selected) together constitute an almost identical picture and gives a good basis for assessing the overall extent of this spalling damage on a proportional basis, i.e. at around 13.4% of all beam ends over the entire guideway. For a total of 761 beam ends surveyed out of 11252 beam ends on the entire guideway (i.e. 6.75%), this means that there will currently be an estimated 1508 spalling repairs.

140. On the basis of the assessed split between significant and severe damage given in §136 and § 137 above), we estimate that, of the 1508 repairs, 782 will involve application of a resin or anti-carbonation coating by jacking up the beams and 726 will involve lifting and turning the guideway ladders over to effect a competent repair including cutting back behind the reinforcement and using a proprietary concrete repair system. We emphasise that these numbers are only estimates and actual quantities can only be determined by a physical inspection of every beam end.

141. The repair of the spalling beams comprises substantive work to repair the guiderails. Details are shown in Drawing 6 in Appendix H. We envisage that this will probably entail dis-assembly of the ladders and inverting the beams to access the damage and carry out a competent repair. We estimate that this could take 3 to 4 days per ladder and would mean closing the guideway.

CRACKING OVER CENTRAL SUPPORTS

142. Calculations based on revised guideway ladder stiffness assessed from Investigation A show that surface crack widths are excessive in the top of the guideway beam, through the central supported area, and in the bottom of the guideway beam through the mid spans between the end and central supports.

143. These cracks will require to be injected at the running surface with resin of appropriate viscosity or similar process. We consider that it will suffice to paint the underside/soffit of the guiderails with bitumen paint.

SUDDEN RAMPS/STEPS AT SLAB INTERFACES

144. A slab interface occurs at the junction of a guideway ladder with an in situ concrete slab. They are located at road crossings and burst throughs where the busway becomes unguided.

145. The levelling surveys carried out in Investigation D identified sudden ramps/steps at slab interfaces some of which are greater than 12mm. Some of these are associated with bearing/shim loss but we believe that others may be related to a construction defect with the in situ guiderail/slab being laid high and then the very end being ramped down to the joint as illustrated in the photograph below.

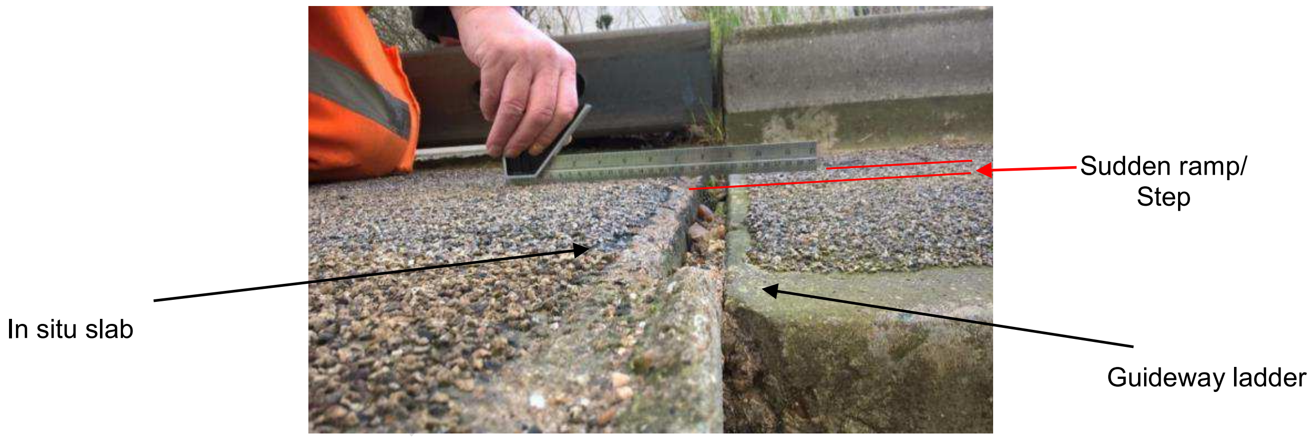

Figure 22. Step at joint between guiderail and insitu slab

146. We consider this to be a Defect as it is not in accordance with the Works Information in the following respects:

   (i) Appendix 7/1, paragraph 14, Table 14.2 which permits no surface irregularities greater than 7mm; and

   (ii) Appendix 7/1, paragraph 21 which requires the vertical alignment to be with ±6mm of the design alignment.

147. Furthermore, paragraph 15 of Appendix 7/1 states, "*At junctions between the busway and public highway, the longitudinal and transverse surface regularity of the busway shall take precedence to ensure the ride quality of the busway is maintained*." It is our view that the ride quality is not maintained at several slab interfaces.

148. We envisage correction of this Defect will be by scarifying or reconstructing the in-situ concrete slab.

THE NOTIFIED DEFECTS

149. The investigations have provided additional information as to the causes of the Defects, but the Defects remain Defects because either the construction is not in accordance with the Works Information or because it is now known it is not in accordance with the accepted design.

150. The following table summarises the Defects notified together with the implications derived from the investigations:

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DEFECT REFERENCE(S)	DEFECT DESCRIPTION	INVESTIGATION AND/OR APPRAISAL EVIDENCE	CONCLUSION(S)	POSSIBLE REMEDY
DEF 293	Lack of longitudinal restraint from shallow foundations.	Investigation I, braking tests, showed that the guideway ladders do not permanently displace under full emergency braking, from 56 mph to a stop, of an ABS equipped, equivalent fully-loaded double decker bus. There is, however, uncertainty about performance of the guideway in the longer term and with the possiblity of heavier buses. There is also evidence that there is a lack of longitudinal restraint such that the ladders are moving with gaps at most of the fixed ends.	Difference between simplistic theoretical assumptions and practice. Design assumptions exclude, for example: i. factors of safety ii. external constraint variables such as: • soil/drainage media, friction against ladders • soil/drainage media, passive pressures (restraint) against ladders and foundations • overall ladder interaction, additional bearings contributing along length of the guideway	Provide longitudinal restraint theoretically capable of accommodating horizontal loads. This includes intoducing ‘tied joints’ in place of the ‘fixed’ joints.
DEF 290	Lack of longitudinal restraint from screw pile foundations.			
DEF 294 & 294a	Lack of longitudinal restraint from brackets.			
DEF 284	Lack of longitudinal restraint from consecutive free ends.			
DEF 268	Lack of longitudinal restraint from flawed fixed end design and/or construction.			

DEFECT REFERENCE(S)	DEFECT DESCRIPTION	INVESTIGATION AND/OR APPRAISAL EVIDENCE	CONCLUSION(S)	POSSIBLE REMEDY
DEF 168, 193, 196, 250 to 256, 260, 263, 264, 272, 276, 277, 279, 280, 281, 282 & 287A	Bearing displacement and loss of bearings/shims.	Investigations B and F indicate that shims and/or bearings can come out. Investigation G indicates that the interface friction between concrete, shim and bearing elements can be below the minimum value specified for shim to bearing interface requirements. Analysis shows that there is inadequate frictional resistance to adequately restrain the bearing – fails to comply with BS5400 Part 9.1.	Guideway ladder does not have have and/or retain sufficient minimum permanent loading to shims and bearings, particulary those at the ladder ends. This is exacerbated under transient imposed (bus) loading as well as full design vertical and/or transverse movement allowance. Interface friction between concrete, shim & bearing elements is insufficient in all circumstances, whether there is out-of-planeness in the guideway ladders or not. Displacement of a bearing can occur on a level ladder arrangement due solely to thermal expansion/contraction effects alone.	Fix (bond) bearings to foundations and restrain shims to prevent the shims and/or bearings from displacing / ‘walking’ and coming out.
DEF 288A	Lack of lateral restraint resulting in excessive lateral steps in upstand guide faces.	Investigation E indicates that the lateral restraint brackets are substantially below the required capacity.	Inadequate design.	Introduce new lateral restraint bracket.
DEF 279, 282 & 283	Foundation Type 1 to Type 2 interface.	Not investigated, but photographed.	The spacer block is unstable, being loosely laid on the precast foundation pad, and cannot transmit the loads adequately.	Bed the spacer block on epoxy mortar to bond it to the pad foundation.
DEF 009	Reduced gap widths at free end joints.	Investigation H suggests that gaps require to be at least 10mm	Preference is to ensure gaps at all so called fixed ends to allow for beam rotation and avoid spalling.	Ensure gap widths at free ends, nominally a minimum of 15mm at 15^0C, during remedial works.

DEFECT REFERENCE(S)	DEFECT DESCRIPTION	INVESTIGATION AND/OR APPRAISAL EVIDENCE	CONCLUSION(S)	POSSIBLE REMEDY
DEF 289	Excessive crack widths in guideway beams (>0.25 mm).	Calculations based on revised stiffness assessed from Investigation A show that surface crack widths are excessive in the top of the guideway beam, through the central supported area, and in the bottom of the guideway beam through the mid spans between the end and central supports.	Inadequate design.	Sealing/injection of cracks in running surface with resin and sealing of soffit cracks with bitumen paint.
DEF 292	Non-functioning guideway drainage – not as designed.	Not reviewed by Invesigations.	Not in accordance with the accepted design.	Correct drainage with adequate outfall.
DEF 295	Non-functioning guideway drainage – design does not accommodate soils of low permeability at Histon.	Not reviewed by Invesigations.	Inadequate design.	Revise drainage arrangements.

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DEFECTS THAT COULD BE NOTIFIED

151. The following table summarises the Defects that could in our opinion be notified:

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NEW POTENTIAL DEFECT	DEFECT DESCRIPTION	INVESTIGATION EVIDENCE	CONCLUSION(S)	POSSIBLE REMEDY
DEF ___	Guideway ladder stiffness does not accommodate 25 mm vertical and 10 mm lateral differential movement stated in the DDG Rev 6 design document.	Investigation A analysis indicates that the guideway beams can only accept equivalent of about 12mm differential settlement (relative to central support) at both ends longitudinally and about 4mm laterally.	Inadequate design.	Reduce potential foundation movements foundations such as pad foundations compliant with NHBC depths. In addition, accept unpredictable amount of re- shimming when there is rocking or see-sawing of guideway ladders.
DEF ___	Spalling located behind restraint brackets.	Investigation K shows that about 6.75% of beam ends have significant or severe spalling.	Loading concentrated locally as a line load or point load at interface between the concrete guideway beams and steel lateral restraint brackets. The resulting stress concentration causes the concrete to locally break off.	Repair areas of significant and severe spalling with proprietary concrete repair material. Insert plastic shims between new lateral restraint bracket and guiderails to remove localised hard points.
DEF ___	Sudden ramps/steps in excess of 2 mm located at slab interfaces.	Investigation C & D demonstrates out-of-tolerance running surface/slab interface levels.	Not in accordance with the Works Information.	Scarify or reconstruct slab.

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REASONS WHY THE DEFECTS REQUIRE TO BE ADDRESSED

Guideway Ladder Defects (GUD)

152. Defects 268, 284, 287, 288, 290, 293, 294 & 294a, with the exception of drainage Defects DEF 292 & 295, have been collectively described as 'The Grand Unified Defect' or 'GUD' because the design is fundamentally flawed. Proposed remedial measures essentially deal with individual Defects collectively; a solution dealing with one Defect actually deals with several at the same time. The Defects relate primarily to displacement of bearing pads and shims and a lack of longitudinal restraint and lateral restraint. In our opinion, a general lack of longitudinal restraint (a Defect previously notified and having several causes) can only be accommodated with the present articulation/fixity arrangement if CCC decides that buses greater than 18.0 tonnes gross weight will not be used on the busway. In any event, it is necessary for the bearing pads and shims to be prevented from coming out.

153. Remedial measures and/or periodic reactive repairs are required because there are ongoing problems with the guideway and its operation. The fundamental problem is that bearings and shims are coming out resulting in steps in the guideway running surface. These steps require temporary speed restrictions to be imposed on the buses until the bearings/shims have been relocated. The bearing/shim relocation involves jacking up the guideway ladders, and generally has to be carried out at night time. We believe that thermal expansion/contraction is the main cause of shims and bearing pads being displaced due to a lack of the friction required to retain them in position. The mechanism by which thermal expansion/contraction can work the bearings/shims out is shown diagrammatically in Appendix B. Previous maintenance works and Investigation F1 have shown several significantly displaced shims and bearing pads, and that survey B1 indicates that some 20% of the shims have moved significantly relative to the bearing pads since January 2014. In addition, the investigations have revealed that the guideway ladders are much stiffer than was assumed in the design. The design document had indicated that the guideway could accommodate (post-construction) 25mm differential movement between foundations longitudinally and 10mm tilt across a foundation pad transversely. It is now evident that this is incorrect; only significantly lower foundation movements can be accommodated. Slight foundation movements can affect the bearing reactions considerably which in turn exacerbates the bearing and/or shim displacements due to thermal expansion and contraction. We also believe these lower movements have been frequently exceeded such that the ladders can rock or see-saw, possibly causing the shims and bearing pads to be vibrated/bounced out of position.

154. Lateral displacements are also occurring. These give rise to horizontal steps in the guiderail upstands with associated speed restrictions. Investigation E has shown that the lateral restraint brackets have maximum lateral restraint capacities severely below the design capacity of 50kN required by the Works Information. In addition to these issues, there are problems of cracking and spalling of concrete that require to be addressed and we believe this will have a significant impact on the time to carry out the remedial works. Guideway Ladders Remedial Works section commences at §171.

Drainage Defects

155. The drainage Defects in the Histon area have not as yet been addressed and should, in our view, be corrected as soon as possible because of their potential impact on the foundations, i.e. softening of clays and a risk of future further foundation movement.

Foundations – Defect 016 and 016a

156. The Works Information required BAMN to comply with the Highways Agency document BD74/00 Foundations and the associated British Standard BS 8006:1996 Foundations. Annex A of BD74/00 updates the British Standard. This requires the designer to use the National House Building Council ('NHBC') 2006 Standard Chapter 4.2 'Building near Trees', to determine the depth of foundation. This standard is based on extensive records of movement of house foundations in the vicinity of trees.

157. BAMN's February 2011 Geotechnical Report states it did not adopt the NHBC Standard; it chose to adopt for the shallow foundations it constructed what it called "50% NHBC", that is, the foundation depth was to be half way between the NHBC depth if no trees were present and the NHBC depth if there was a tree nearby. For example if the NHBC standard required a depth of a foundation to be 2 m due to a tree and 1 m if the tree was not present, BAMN would have used a depth of 1.5m. In our opinion, this design approach was flawed.

158. The design document had indicated that the guideway could accommodate 25mm differential movement between foundations longitudinally and 10mm tilt across a foundation pad transversely. In our September 2014 report we considered that on the basis of the design document statement on acceptable movements it was reasonable to accept foundation depths slightly shallower than NHBC depth foundations but not "50% NHBC" as the latter would potentially cause greater movements than the maximum 25mm between and 10mm across supports. Thus it still meant a substantial number of foundations were of inadequate depth. The foundation design as stated in BAMN's February 2011 Geotechnical Report did not comply with the Works Information and substantially raised the risk of settlement/heave affecting the foundations and the magnitude of the differential movement between foundations.

159. The results of the investigations have shown the guideway ladders to be significantly stiffer than expected and designed for. This means they can now only tolerate significantly lower foundation movements than previously indicated by BAMN in its design.

160. Given the low tolerances on movement that can be accommodated by the existing guideway ladders, in our opinion, a revised shallow foundation design alone would not correct the Defects as the differential settlement limits are below the value that we believe can be accommodated by the NHBC depth determination, and below that which can be reasonably estimated by calculation due to the number of variables (known and estimated) such as, soil type and properties, tree type and root locations and weather.

161. We consider that if the foundation Defects are left uncorrected, future movements will lead to substantially reduced loads on the some of the bearings under the guiderails that will lead to further displacement of bearing and/or shims.

Determination of extent of defective foundations requiring correction

162. Our previous estimation of the number of shallow foundations requiring remedial works given in the September 2014 report was based on the BAM Nuttall's DDG6 document differential settlement limits.

163. It is our view, from accumulated experience, that NHBC foundation depths generally allow up to 15mm of differential movement. Given the sensitivity of the guideway ladders, in their existing condition, limits on longitudinal and lateral differential settlements will be considerably lower than tolerated by the NHBC depth determinations. In our view without the guideway ladders being made more flexible all foundations on shrinkable ground will need to be piled to avoid potential excessive movement. This would be an expensive and highly disruptive activity.

164. We have thus, in assessing the extent of the foundations requiring correction, assumed that remedial works will be undertaken to the guideway ladders to allow them to tolerate movements in line with either the movements that we consider NHBC foundation depths would allow or the original design intent.

165. We have also since September 2014 undertaken detailed assessment of the ground conditions by examining the various ground investigations and modelling ground conditions for each foundation rather than utilise the zonation of the site as developed by BAMN. We have also further examined the existing tree locations to estimate the number of NHBC compliant and non-compliant foundations over the northern section based on the original centreline ground level. Our current estimate is that this would result in 821 non-compliant foundation locations (i.e. across both tracks) – there are 1795 shallow foundation locations in the northern section (excluding Orchard Park), so just under half have to be deepened. It is our current opinion, that this would be a worst case scenario. A best case scenario is not feasible to determine as the precise root development of existing trees, any management of the trees by third parties, the mortality rate and timing of such mortality and climatic changes are not predictable.

166. It should be noted that remediating the foundations to NHBC compliant depths will not resolve the problems relating to the superstructure. In our view settlement will by this means be limited to up to 15mm at one end only of a guideway ladderand whilst this is likely in our view to avoid much possible future see-sawing of the guideway ladders, the cracking over the central support is likely to increase (we have calculated this to be around 0.3mm), and would necessitate realignment of the guideway by re-shimming. In addition, lateral settlement could also still occur resulting in rocking of the guideway ladders and similarly necessitating realignment of the guideway by re-shimming.

167. If foundations are not remediated to NHBC compliant depths, then frequent development of see-sawing and rocking of the guideway ladders can be expected that will result in the need for more frequent re-adjustment of the guideway levels over the design life of the guideway – shims would have to be added or removed to accommodate seasonal upward and downward movement of the foundations.

TIME RELATED IMPACT OF NON-CORRECTION OF DEFECTS

Guideway Ladders

168. If Defects are not corrected by means of a remedial scheme, then it is highly likely that bearing/shim losses at joints will continue to manifest. In our view, to a large degree this will be associated with foundation movement but this is not always the case, and steps have formed at joints where the guideway ladder is not out-of-plane laterally by more than 1mm to 2mm (e.g. chainages 9673 to 9688 F and 41733 to 41748 T).[7] We consider that the cause of the latter is the lack of friction to resist horizontal movements due to thermal expansion/contraction. The mechanism for this is shown in Appendix G.

169. We regret that we are unable to provide meaningful prediction of bearing/shim loss in the future if a remedial scheme is not implemented, though we believe it will be widespread. This unpredictability is because there are so many variables and unknowns relating to ground conditions, seasonal variations, tree root growth etc. and, most importantly, very little foundation movement (say 2mm transversely and longitudinally either 12mm differential settlement between guiderail ends relative to the central support, or 6mm heave at guiderail centre) is needed to severely affect bearing/shim stability, reducing reactions by around 50% at one or more supports. In addition, these will impact to varying degrees depending on what twist has already occurred (or was constructed) in the guideway ladders. We would expect, however, given the results of Investigation D, for at least one third of bearings (say two diagonally opposite placed end bearings per ladder) over 95% of the guideway to be affected over the life of the guideway. It could, however, be more than this given the effects of thermal expansion/contraction generally for which there is insufficient vertical load on the supports (even for an ‘in-plane’ ladder) to develop the required frictional resistance to keep the bearings/shims in place.

Guideway Foundations

170. Our concern is that with no remedial works, even minor localised changes to the groundwater regime may lead to differential foundation movements in excess of those referred to in §169 above. In our view, it is not possible to predict with sufficient reliability where and when that might happen except that it is reasonable to assume that maximum settlement movements are most likely to occur during or towards the end of a long hot summer where vegetation is close by.

[7] T = towards Cambridge, F = from Cambridge

GUIDEWAY LADDER REMEDIAL WORKS

171. Unless a risk is taken on a reactive approach to 'make do and mend' when significant defects, steps etc. arise (which we are unable to quantify on account of the extremely sensitive behaviour of the ladder assemblies to ground movement and thermal effects), there are, in our view, three principal Options available in remedying the superstructure:

(i) We have commented on the torsional rigidity of the existing ladders at §57 to §64 above. We initially considered the concept of pinning four of the six spacer/guiderail connections and this led to evaluation of this concept, especially in relation to the effect on transverse loading of 50kN applied to the ladders. Whilst the principle of changing the articulation is preferred in permitting the guideway superstructure to better accommodate transverse foundation movement, we have found from further analyses that this induces problems in accommodating the design 50kN lateral load which gives rise to unacceptable forces/moments being taken on a single spacer. We therefore do not propose to change the articulation but this may mean that small foundation movements may necessitate re-shimming by CCC on a possible regular basis to limit rocking of the ladders, though we are unable to quantify the frequency of this. This is due to the unknown level of distortion and tilt of the guideway ladders on construction and subsequent adjustment by BAMN and the inability to reliably predict with any precision such small movements. The small foundation movements that can lead to this issue cannot be definitively prevented by the construction of the foundations to full NHBC depth.

The option is therefore to alter the guideway ladder construction and design by providing restraint to bearings/shims and tying the fixed joints together with a gap to permit rotation and avoid spalling. This would, in allowing a minimum nominal load reaction at guiderail end supports of approaching zero, involve carrying out foundation works to limit differential movement between foundations longitudinally to 15mm settlement at ends of guideway ladders (or 9mm heave in centre of guideway ladders[8]). This approach will require all foundations to comply with the full NHBC depths. We recommend this approach, although some re-shimming to limit rocking of the guideway ladders is still likely to be required to an unpredictable extent. In addition to bearing/shim restraint would be provision of lateral restraint at all guiderail joints.

(ii) Adopt a reactive approach, such that the remedial works outlined in Option (i) are only carried out when bearing and/or shim loss and/or rocking of guideway ladders occurs and/or lateral steps at joints becomes excessive such that emergency works are thereby required. This would have the disadvantage of CCC implementing an unplannable repair regime which could be expected to be required over most of the remaining 35 year life of the guideway. Given the required works to foundations as detailed in (ii) above, we believe that such an approach would incur an unknown, but inevitably unacceptable number and frequency of disruption events to bus operations.

(iii) Adopt a reactive approach to the remediation of the guideway ladders outlined in Option (i) but undertake no remedial works to the foundations to minimise disruption to busway operations. Some foundations are anticipated to settle. Consequently, it can be expected that, even after carrying out

[8] Except between chainages 17531 and 17901 continued heave in excess of 9 mm is not expected to occur.

guideway ladder remedial works, further foundation movement will occur that will necessitate jacking up of guiderail ladders and re-shimming to restore the guideway alignment and ride quality. If settlement of foundations occurs that leads to an excessive overall thickness shims (>35mm as defined at note 10 on Drg No. CGB/GD/B/010Z), it will be necessary to install a concrete pad below the elastomeric bearing pad.

Providing bearing/shim restraint

172. Our current thinking is, having supported the guideway ladder on jacks and removed the bearing/shims, to core a single hole (say 38mm diameter) down through the centre and ends of the guiderail at the centre of each bearing and down into the foundation, a process called dowelling. The shims and elastomeric pad would also be drilled (also 38mm diameter) at their centre. A 20mm (say) stainless steel bar would then be inserted down the hole in the guiderail, through the drilled holes in the replaced shims and bearing pad and into the foundation. The bar does not need to be fixed into the foundation concrete, since its purpose is merely to prevent the bearing pads and/or shims from creeping out. From an operational viewpoint, the bar could be threaded at the top so that the bar can be removed with a threaded socket key should this be necessary to remove or add shims at a later date due to foundation movement. A rubber disk is placed in the hole in the foundation pad would help to prevent the bar from rotating during the removal process. A neoprene plug would then be placed in the hole at the running surface to seal the surface and prevent detritus entering the hole. Details are shown in drawings, Drawings 1 to 3 in Appendix H.

Providing longitudinal restraint

173. Longitudinal restraint is provided by tying two guideway ladders together at the 'fixed' ends such that longitudinal forces are accommodated by 12 bearings. Details of the tied joints are shown on Drawing 4 in Appendix H.

Providing lateral restraint

174. Dowelling of the supports described in §172 above would only provide notional restraint laterally. To positively restrain the guideway ladders laterally and to prevent steps occurring in the guide faces, we recommend installing new restraint brackets bolted to the foundation concrete. Details are shown in Drawing 5 in Appendix H.

Consideration of Construction Trials

175. If a proactive approach is preferred (as opposed to reactive works), consideration could be given to carrying out works to a small section of guideway to test the practicality of construction method(s) as well as effectiveness of the design.

Addressing foundation movement (assuming foundation works are not implemented)

176. If pad foundations are not remedied to control the amount of settlement and/or heave, then significant movement can be expected in certain locations. Where settlement is excessive, re-shimming alone may not be sufficient and consideration may need to be given to inserting a concrete block beneath the bearing pad to limit excessive overall shim thickness, currently specified by BAMN's design as 35mm maximum.

Addressing other Defects

177. There will be other Defects that will require to be addressed such as spalling repairs, filling of cracks, and drainage works, irrespective of which remedial option is recommended.

178. Not carrying out spalling repairs at the running surfaces and guide faces would adversely impact on ride quality, and not carrying out repairs to the larger spalling areas identified in Investigation K behind the lateral restraint brackets is likely to adversely affect durability of the guideway in terms of corroding reinforcement. Suggested details/methodology for carrying out the repairs to the bottom of guiderails are shown in Drawing 6 in Appendix H. We estimate that such repairs (to severe spalling) will be required at some 726 beam ends with repairs to lesser significant spalling involving resin coating at some 782 beam ends.

179. As indicated above, Investigation K has revealed a problem of significant and severe spalling behind some 13.5% of the lateral restraint brackets investigated. We recommend that plastic shims or elastomeric pads are positioned between the new lateral restraint assemblies and the concrete guiderails to lessen the risk of point loads on the concrete and consequential spalling.

180. Drainage works are required because waterlogging/ponding is evident around the foundations in certain locations which adversely affects the performance of the foundations.

181. In the light of the foregoing, we consider that significant future expenditure on the guideway will be necessary for its continued satisfactory operation.

Inspection and maintenance

182. The current design does not allow for inspection of the condition of the restraint brackets and associated spalling or the condition of the bearings and shims without the removal of the shredded tyre drainage media. In our opinion, inspection chambers should be installed to allow the inspection of these components and should have been included within the orginal works given the inspection regime proposod by BAMN. Consideration should also be given to providing access to facilitate the addition or removal of shims.

183. An inspection regime should be implemented based on the adopted remedial option. In our opinion a walkover survey (checking and measuring steps in guiderails) and an annual condition survey (inspecting the restraint brackets for spalling and for bearing and shim movement) is necessary for all Options.

184. Where foundation movement is expected to result in the need for shims to be added or removed further remedial work will be necessary.

Engineering Methodology for Remedial Options

Restrain bearings and shims and provide longitudinal and lateral restraint, Option (i)

185. This approach will require all foundations to comply with the full NHBC depths and a long term inspection and maintenance regime to manage the risk that bearings and shims could still displace.

186. This option would therefore comprise;

(i) Detailed design of remedial solution;

(ii) Progressive closure of the sections of guided busway to all users (night shift could be utilised for superstructure only works, full closure for foundation works and if spalling repairs are required to the bottom of guiderails);

(iii) Excavation of the drainage layer;

(iv) Remediate guideway ladders;

a. Raise guideway ladder;

b. Turn over or disassemble;

c. Repair spalling as in §141 above;

d. Reassemble and/or turn over;

(v) Remediate foundation;

a. Removal of shallow foundation pads where not to NHBC depth;

b. Excavation to NHBC depth and backfill with selected granular fill;

c. Replacement of foundation pad;

(vi) Lower guideway ladders onto bearings, and level with shims;

(vii) Drill for shim restraint detail, place rubber disk in bottom of hole;

(viii) Jack up, bond bearing pad to foundation and level with shims;

(ix) Install shim restraint detail;

(x) Install tied joint detail to provide longitudinal restraint;

(xi) Install lateral restraint detail;

(xii) Install inspection chambers and backfill drainage media; and

(xiii) Allow for bi-annual walkover inspection and a low number of shimming interventions mainly relating to lateral foundation movement.

187. In our opinion, this option will incur disruption related to CGB closure to 821 chainage locations where foundation deepening is required, and the locations are given in Appendix G. We consider that this option minimises (but does not eliminate) the risk of rocking and/or see-sawing of guideway ladders from the effects of ground movements and traffic loading. The requirement to implement a regime of bi-annual inspection and maintenance would be in order to identify and install/remove shims to allow for seasonal heave/shrinkage of clays and longer term shrinkage of clays due to tree influence.

Reactive guideway bearings/shims restraint and lateral restraint with foundation remediation, Option (ii)

188. The required works to foundations will still be as detailed in (i) above but we believe that the remediation would incur significant disruption to bus operations whenever bearing and/or shim loss necessitates remedial action. In addition, there will be an unknown but probable substantial number and frequency of disruption events to bus operations in needing to carry out re-shimming of the guideway supports when subsequent rocking and/or see-sawing of guideway ladders occurs. This approach will require all foundations on shrinkable ground to comply with the full NHBC depths and a long term inspection and maintenance regime to manage and limit (but not eliminate) the risk of rocking and/or see-sawing of guideway ladders occurring. This option would therefore comprise;

(i) Detailed design of remedial solution. Identify optimal scope of works (number of support locations) to be undertaken on identification of remedial requirements;

(ii) Notification following planned inspection and condition survey or inspection and survey following guideway performance deterioration identification;

(iii) Reactive closure of the sections of guided busway to all users (night shift could be utilised for guideway ladder only works, full closure for foundation works and if spalling repairs are required to the bottom of guiderails);

(iv) Excavation of the drainage layer;

(v) Remediate guideway ladder

  a. Raise guideway ladder;

  b. Repair spalling as detailed in §141 above;

(vi) Concurrently remediate guideway foundation;

(vii) Removal of shallow foundation pads where not to NHBC depth;

(viii) Excavation to NHBC depth and backfill with selected granular fill;

(ix) Replacement of foundation pad;

(x) Drill for shim restraint detail, place rubber disk in bottom of hole;

(xi) Jack up, bond bearing pad to foundation and level with shims;

(xii) Install shim restraint detail;

(xiii) Install tied joint detail to provide longitudinal restraint;

(xiv) Install tied joint detail to provide longitudinal restraint;

(xv) Install lateral restraint detail;

(xvi) Install inspection chambers and backfill drainage media; and

(xvii) Allow for quarterly walkover inspection and a low number of shimming interventions mainly relating to lateral foundation movement.

189. In our opinion, this option reduces the disruption related to CGB closure to 821 chainage locations where foundation deepening is required. There will be a requirement to implement an intensive regime of inspection and maintenance in order to identify remedial interventions and to install/remove shims for seasonal heave/shrinkage of clays and longer term shrinkage of clays due to tree influence.

Reactive guideway bearings/shims restraint, no foundation remediation, Option (iii)

190. We expect that, following guideway ladder remedial works, further foundation movement will probably occur necessitating repeat or multiple re-shimming to restore the guideway alignment and ride quality. Further significant settlement of foundations may occur with time, leading to an excessive overall thickness of shims requiring the installation of a fixed concrete (or structural) pad below the elastomeric bearing pad. This option would therefore comprise;

(i) Detailed design of remedial solution. Identify optimal scope of works (number of locations) to be undertaken on identification of remedial requirements;

(ii) Notification following planned inspection and condition survey or inspection and survey following guideway performance deterioration identification;

(iii) Reactive closure of the sections of guided busway to all users (night shift could be utilised for guideway ladder only works, full closure if spalling repairs are required to the bottom of guiderails);

(iv) Excavation of the drainage layer;

(v) Remediate guideway ladder;

(vi) Raise guideway ladder;

(vii) Repair spalling as detailed in §141 above;

(viii) Lower guideway ladders onto foundation;

(ix) Drill for shim restraint detail, place rubber disk in bottom of hole;

(x) Jack up, bond bearing pad to foundation and level with shims;

(xi) Install shim restraint detail;

(xii) Install tied joint detail to provide longitudinal restraint;

(xiii) Install lateral restraint detail;

(xiv) Install inspection chambers and backfill drainage media; and

(xv) Allow for quarterly walkover inspection and a number of shimming interventions relating to foundations not to NHBC depth and/or lateral foundation movement.

191. In our opinion, this option will limit the disruption associated with CGB closure as no foundation deepening is required but there would be significant disruption partly because spalling repairs are required to the bottom of the guiderails. With no foundation remediation, there will be an increased risk of rocking and/or see-sawing of guideway ladders. Consequently, there will be a requirement to implement an intense regime of inspection and maintenance in order to identify remedial interventions and to install/remove shims for seasonal heave/shrinkage of clays and longer term shrinkage of clays due to tree influence.

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APPENDIX A – CURRICULUM VITAE

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CURRICULUM VITAE

Name: **Anthony Cort**
BSc(Eng), CEng, MICE, MCIHT
Nationality: British
Profession: Civil Engineer
Position in Firm: Associate Director

Key Expertise: Tony has acted as an expert witness/advisor on countless occasions since 1985, has written numerous reports, and has appeared in court to give evidence on several occasions. He has also been instructed several times as a Single Joint Expert.

He has experience in the design and construction of highways and bridges including acting as an expert associated with two guided busway projects. He has key expertise in investigation of curtain wall failures/corrosion, building refurbishments, concrete, steelwork (including repair & refurbishment), steel corrosion and protection, structures, watertight basements, piling, and ground engineering.

Tony has a special interest in carrying out drainage assessments (foul and surface water and highway drainage), and in reporting of drainage problems and appraisal of flooding cases.

Experienced in contract administration and contractual claims.

Tony has investigated and reported on drainage issues in relation to various highway and retail distribution centres and in relation to flexible and concrete pavements in the UK.

Education/ Professional: 1965: BSc(Eng) in Civil Engineering at Queen Mary College, University of London

Qualifications:
1970: Chartered Engineer
1970: Member of Institution of Civil Engineers
1981: Member of Chartered Institution of Highways and Transportation

Experience Record:

Capita June 2008 onwards

Associate Director

Recently provided expert advice and expert evidence on on a major UK highway dispute involving drainage, and also major pavement failures essentially related to drainage issues.
Has been engaged on a wide range of expert appointments including:

- As a party-appointed expert on guided busways involving alignment, drainage and structural issues;
- As a party-appointed expert on several road traffic collisions involving highway conditions/drainage;
- As a party-appointed expert on a hotel development with a structural failure of the basement
- As a party-appointed expert on a major UK highway dispute involving drainage;
- As a party-appointed expert on building defects in various buildings;
- As a party-appointed expert on a new housing development subject to flooding;

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- As a party-appointed expert on numerous cases involving flooding and drainage problems, including highway drainage design and maintenance.

Jacobs UK Ltd 2004 to 2008

Senior Consultant, Technical Director

Expert Witness including legal cases relating to drainage and flooding including road traffic collisions, contractual claims and advice, project design reviews and risk assessments, including advice to householders regarding tunnelling proposals beneath properties. Other cases included investigation of structural failures, scaffolding collapse, roofing failures, water supply disputes, flooding of buildings, drainage defects, highway drainage, concrete slab failures, piling failures, foundation failures, etc.
Acted both as single joint expert and expert to single party.
Design reviews within office including pile design, pile capacities, highway drainage, marine structures.
Contract administration including final accounts and assisting contractors with claims, including multi million high rise buildings. Expert Witness to contractors seeking redress from designers

Babtie Group Ltd 2002 to 2004

Technical Director

Moved to form part of a new team of expert witnesses to develop this new specialism within the group.
Cases involved highway assessments, highway drainage design defects, highway alignments, flooding disputes, drainage problems (foul and surface water), structural failures, scaffolding collapse, waterproofing to basements, disputes involving concrete, drainage, asbestos, cracking in roof cladding, and building and domestic property disputes. Problems also included corrosion of steel curtain walling/cladding and failure of concrete cladding units. Specific cases have included dealing with foul sewer issues with properties.

Maintained significant involvement in major civil engineering construction projects involving project management, claims assessments, project verification, design reviews, and advice to design teams.
Peer review of piling on multi-million ferry terminal extension together with management assessments associated with additional services. Surveys of properties including condition surveys and drainage surveys including condition of pipework and tanks.

1995 to 2002

Responsible for the structural engineering section in the Group's Cardiff Office including business development and bid submissions.

Extensively involved in contract administration and dispute resolution, and expert witness work. Director responsible for marine works (including refurbishment of a Victorian pier, marina sheet piling at Poole, and ferry terminal expansion at Pembroke Dock), involving extensive refurbishment/grit blasting of existing steelwork. Advice on steelwork corrosion and protection.

Advice/project monitor to Millennium Commission for various projects including Millennium Stadium Cardiff, Millennium Coastal Park Llanelli, and Marine Environment Centre, Swansea. Engineer to £45m Main Civil Works Contract for power station including valuation/certification and dispute resolution.

1990 to 1995

Director responsible for the management of Cardiff Office in addition to the structures team. Responsible for cost control, planning, submissions, marketing and client liaison.
Experience includes dealing with the preparation of various capital projects including building and civil engineering structures; marine projects; drainage schemes. Project Director for building structures (including building refurbishments and extensions), building and civil drainage and external works/pavings, sheet pile structures, foundation structures, piled foundations, reinforced concrete design, water retaining structures including building basements and lift shafts, foul sewer storage tunnel in Cardiff.
Structural inspections of buildings together with strengthening of cooling towers, bridge inspections, and condition surveys/refurbishment of marine structures including seaside piers and berthing facilities.
Design of marine structures and refurbishment of buildings including listed buildings. Identification and repair proposals for water ingress and damp problems in properties.

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Dobbie and Partners 1985 to 1990

Associate

Associate responsible for the development of Barry Old Harbour incorporating new lock, breakwater, land reclamation and infrastructure. Foundation strengthening schemes for cooling towers at Ratcliffe-on-Soar and Fiddlers Ferry Power stations.

Miscellaneous foul sewerage schemes including tunnels and pipe jack construction.

The position involved a management role within the office including staff administration, cost control, planning and promotion and liaison with clients. Specific responsibility for structures (civil and building) and for marketing.

Principal Engineer 1977 to 1985

Principal Engineer with responsibility for reports, design work and administration for site investigations, highways, sewerage and flood alleviation projects and building structures for United Kingdom and overseas, including design and construction administration of foundations, design and remedial works to foundations in varying ground conditions. Piled foundation design. Responsible for Kidwelly rail washery project including replacement and realignment of tracks, rail structures and coal washery buildings.

Structures design in Middle East included reinforced concrete framed office blocks, mosques and large villas with swimming pools.

Design and build structures projects including supermarket and miscellaneous building structures.

Expert consultancy on hydrological and hydraulic studies, including analysis and regression of local data, rainfall run off estimations both in United Kingdom and Middle East.

Contract administration and claims assessment.

Computer development and usage within firm including development of design software packages for hydraulics, highways and structures. Participation in local computer seminars.

Overseas experience includes nine months in Africa and the Middle East in connection with structures, highways design and office management.

Senior Engineer 1974 to 1977

Team Leader for design of Furnace and Eglwys Fach Bypass including assistance at public inquiry.

Traffic engineering and preliminary reports for approach roads to Aberystwyth including traffic assignment and economic analysis.

Site investigations including general geotechnical appreciation and reporting for various aspects of engineering and housing projects.

Involvement in preparation of trunk foul sewer schemes and associated structures.

Rendel Palmer and Tritton 1969 to 1974

Engineer

Time spent on site as Section Engineer and Deputy Resident Engineer on the Cardiff-Merthyr A470 Trunk Road with experience on the construction of own bridge designs, railway bridge and working adjacent to and over rail tracks.

Design Engineer 1968 to 1969

Design Engineer with Rendel Palmer and Tritton, period spent in the design of bridge structures (including rail), retaining walls and vertical and horizontal alignments for road works.

Trainee Engineer 1965 to 1968

Trainee Engineer with Rendel Palmer and Tritton in bridge design section, becoming responsible for design of various bridge types on Cardiff - Merthyr A470 Trunk Road (7 No. bridges in total).

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Specialist experience in expert witness and advisory services:

Site supervision, contract administration and claims assessments (including delay evaluation) of major civil engineering contracts including piling and groundworks.

Extensive knowledge of CDM Regulations, reviewing of risk assessments, Planning Supervisor role on contracts. Holder of Manager CSCS card.

Examples of contract administration and claims assessment in last 15 years:

- £3m Foul sewer storage tunnel (lined segmental construction 3 metre diameter) in South Wales
- £10m Flood alleviation contracts on River Ebbw in South Wales
- £2.5m Refurbishment of pleasure pier
- £7m Ferry terminal extension at Pembroke Dock
- £48m main civil works for gas turbine power station

Overseas Experience:

Overseas experience includes nine months in Africa and the Middle East in connection with structures, highways design and contracts, and office management.

Worked extensively in Libya and Oman.

expert witness and advisory services

CURRICULUM VITAE

Name:	**Andrew J Hallum** BSc(Hons), CEng, MICE, MIStructE, ACIArb
Nationality:	British
Profession:	Chartered engineer
Position in Firm:	Associate Director

Key expertise:

Andrew is an experienced designer and design manager for both civil and structural projects. He graduated in 1986 and has since acquired expertise in the surveying, appraisal and repair of both recent and historic buildings and structures. He is a chartered civil and structural engineer and also an associate member of the chartered institute of arbitrators.

His knowledge includes masonry, concrete, timber, steel, wrought and cast iron. His broader and practical experience covers car parks, office blocks, schools, hospices and hospitals, housing, commercial, industrial, wastewater treatment projects and bridges. His design office experience, combined with periods on site, provide him an understanding of the need for sensible and practicable design solutions.

He is a past chairman (2004/2005) of the Institution of Structural Engineers Wales Branch, and is currently a serving committee member and the Wales regional group "Professional Review" coordinator.

Andrew now spends much of his time providing expert advice to clients.

Andrew's areas of expertise include:

- Building structures design, from inception to completion, across many construction market sectors.
- Structural surveys and inspections, forensic appraisals including back analysis, and reporting.
- Building conservation, restoration, renovation, refurbishment and remediation.

Qualifications:

1986:	BSc(Hons) Building Engineering, University of Bath
1992:	Chartered Engineer (CEng)
1992:	Member of the Institution of Civil Engineers (MICE)
1993:	Member of the Institution of Structural Engineers (MIStructE)
2015:	Associate Member of the Chartered Institute of Arbitrators (ACIArb)

Publications and Awards:

- Structural Faults + Repair-99 – "Aberthaw Power Station: Repairs to Fire & Vibration Damaged Turbo Block", co-author.
- IStructE Branch Prize, 2000-2001, for the presentation "Plas Mawr, Conwy – The Conservation and Restoration of an Elizabethan Town House"
- The Structural Engineer (Volume 84, No 6, 21 March 2006) – "Our Role in Conservation"
- IStructE Clancy Prize, May 2007, for the paper "Our Role in Conservation"

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expert witness and advisory services

Expert Witness and Advisory Services, Project examples:

Cambridgeshire Guided Busway

Supported the instructed experts in investigating and preparing expert advice in a c. £100m dispute over alleged defects in, and delays to, this major infrastructure project. Advice related to findings from research and review of original documentation, including the design intent associated with pre-cast, reinforced concrete guideway beams. This included independent modelling and analysis, for comparative purposes against the original design and details. Subsequent support and assistance, in respect of advice for and attendance at investigations to better understand actual behaviour and "defects" of the guideway. This included additional computer modelling and analysis for comparison of results with the site investigation data collected. Assisted in the development of appropriate, indicative remedial works to rectify the problems and defects identified within the original design, detailing and/or construction.

Waste Management Services Site, South Wales

Appointed expert to inspect and advise upon the construction of a roller compacted, cement bound pavement on the site. The slab has to act as an impermeable barrier to effluent resulting from waste management activities carried out across its surface.

Medical Waste Management Centre, UK

Appointed expert to inspect and advise upon several issues at a medical waste management centre. Included fibre reinforced concrete external paving and internal concrete floor slabs.

Ground and Basement Car Park, Water Ingress Issues, Essex

Appointed expert to look at and advise upon water ingress into the basement of a reinforced concrete car park. Issues include the surfacing at ground level, joints between walls and slabs and cracking through the basement walls and ground floor car park deck.

Swimming Pool Frame, Midlands

Initially provided support to the appointed expert. Subsequently appointed as the expert to investigate excessive deflections to the roof structure over a swimming pool. The roof structure comprises glued laminated timber frames and steel trusses which in turn are supported off a mixture of reinforced concrete or steel framing.

Defective Ply Flooring, London

Appointed expert to carry out a brief site visit and inspect ply flooring boards. Provided initial advice on problems that may have arisen to plywood flooring as a result of "defects" included within the boarding as supplied and installed.

Berth Extension and Refurbishment, South Coast Port

Jointly instructed expert providing advice on alleged design defects. The advice related to potential shortcomings in the design and detailing to reinforced concrete elements. These included coping beams, transition slabs and pavement.

CAPITA

expert witness and advisory services

Listed Building, Sussex

Drafted an advisory note, as the instructed expert, in respect of brickwork stability issues. This related to a refurbishment project, to bring about a change of use, to an existing Grade II listed building. During the works part of a wall collapsed and other areas of brickwork were identified as being unstable and/or unsafe. Reviewed the information made available and visited the site. Provided my opinion on the probable causes for the collapse and general instability.

High Rise Development, Dubai

Provided support and advice to the appointed expert for this high-rise, 60-storey, reinforced concrete (rc) building. The building structure comprises three blocks, with "bridge links" between two of these at various levels. Investigating:

- Structural behaviour for two of the steel bridging structures between the rc blocks.
- Interaction / interface between steel and concrete components, taking the effects of differential shrinkage and creep into consideration.

Hospital Site, Bury

Instructed to produce an expert's report on potential causes of water damage following refurbishment works. These related to plumbing works, undertaken as part of the refurbishment, within an existing secure hospital site. Following practical completion several leaks, from joints in the new pipe work, were discovered. I was required to consider whether there were any possible, pre-existent, alternative water and/or moisture sources that could have contributed to or caused the damage found, and subsequently rectified, to various parts of the building fabric.

Metro Link, Midlands

Assisted and advised the appointed expert. Looked into potential structural failure mechanisms for:

- Pre-cast, reinforced concrete, cover slabs
- Pre-cast concrete segment walls
- Concrete base

These related to the provision of new enlarged access shafts / chambers above the line of an existing sewer and along the line of a new metro link.

Midlands Shopping Centre Car Parks – Expansion Joint Defects and Leaks

Provided support to the appointed expert. This included advice in the production of drawings and details for the rectification of defective jointing in the upper decks of a multi-storey car park at a large midlands shopping complex. These defects were as a result of refurbishment works undertaken to the car park.

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Flue Gas Desulphurisation (FGD) Seawater Conditioning at Power Station, South Wales

Assisted and supported the instructed expert in preparing expert advice concerning alleged defects to a very large, in-situ, reinforced concrete desulphurisation tank. Issues included design and construction of concrete mix and reinforcement, within a highly corrosive environment (sulphur dioxide), and remediation of cracks, together with some associated corrosion and loss of reinforcement, during a restricted operational window. Primarily based on site advising on the coordination and supervision of testing and investigations at the site. Also regular meeting attendances, together with the taking independent records of observations and operations whilst on site.

Reinforced Concrete Basement, London Hotel

Assisted the instructed expert in investigating and preparing expert advice in a dispute over defects to the appropriateness of remediation to a reinforced concrete basement. Independent review of the original calculations and design intent included modelling and analysis. This was for comparative purposes together with identifying potential failure mechanisms and/or shortcomings in the original design. Enabled an informed review of the design and details for remediation already undertaken.

Other projects:

Christchurch Hill Overbridge, Caerleon

This reinforced concrete bridge carries the B4236 over the M4 motorway. Carried out an assessment of the existing bridge structure. Determined its actual vehicle load carrying capacity, and ascertained whether a weight restriction needed to be applied.

Hyder Consulting – 1986 to 2000:

H M Prison, Cardiff - New Cell Block Extension

As an Engineer's Representative based full time on site oversaw the sub-structure and superstructure construction packages. The project provided a new five-storey reinforced concrete structure, accommodating cells for an additional two hundred inmates. Responsible for on-site monitoring and overcoming unforeseen problems, including any remedial measures as required.

Swansea WWTW, Sludge Digester Tank

Structural inspection, recording cracking to a reinforced concrete sludge digester tank following an "explosion". The tank had been designed as a pressure vessel and failure of a valve resulted in the vessel becoming sufficiently pressurised to blow off its pre-cast segmental lid. Carried out back analysis, to estimate the potential pressures involved and whether or not failure to any of the reinforcement would then have occurred. Subsequently developed remedial measures.

Plas Mawr, Conwy

Structural survey works, and subsequent conservation works, to this Grade I listed, Elizabethan 1st Town House. Involved detailed site investigations and measurement to enable "back analysis" of remaining timber sections. The project won the 1997 RICS award for building conservation.

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Aberthaw "B" Power Station, South Wales

Site Supervisor, on behalf of National Power, overseeing reinforced concrete repairs to fire damaged turbine block structure. The works were carried out under the New Engineering Contract, Document E: Cost Reimbursable Contract.

Aberthaw "A" Power Station, South Wales

Part of a team that undertook inspections, for cracking and other concrete defects. These were to many of the ageing, reinforced concrete structures which were both on land and out to sea. Several structures were no longer in use and/or operational, being parts of the redundant Aberthaw "A" Power Station.

Malthouse Road Overbridge, Cwmbran

This bridge, in excess of 100m in length and crossing a cutting of up to 12m in depth, was designed as a cast in-situ, reinforced concrete integral bridge. Undertook a Category 3, independent, design check for the structure.

Royal Close, Penarth

Assistance to the lead engineer. Assessment and development of concrete repairs, together with their specification, associated with the refurbishment of several council housing blocks. This also involved dialogue and meetings with specialist concrete repair contractors. Several site visits to witness and inspect the remedial works being undertaken.

Talbot Green By-pass, Rhondda Cynon Taf, South Wales

Seconded to Mid Glamorgan County Council, direct works department, as a site engineer. Had responsibilities for setting out of approximately a one mile section of the highway and associated structures. The structures included a new footbridge and widening to an existing reinforced concrete road bridge over the new highway. My work included the setting out and overseeing of some large reinforced concrete bases and abutments.

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expert witness and advisory services

CURRICULUM VITAE

Name: **Robin Sanders**
BSc(Hons), MSc/DIC, CEng, MIMMM, FIHT, FGS

Nationality: British
Profession: Geotechnical, Environmental and Waste Engineer
Position in Firm: Director

Key Expertise: Extensive experience as director on a wide range of geotechnical, geo-environmental, and waste projects, including the co-ordination of multi-disciplinary teams to achieve completion of commissions within target programmes and within budget.

Expert advisor to insurers and expert witness instructed by solicitors on matters involving infrastructure earthworks, tunnel, landfill, coastal and geotechnical engineering claims.

Education/ Professional:
1974: BSc (Hons) in Geology, Sir John Cass College, London
1979: MSc/DIC in Engineering Geology, Imperial College, London

Qualifications:
1975: Fellow of the Geological Society
1980: Member of the Chartered Institution of Highways and Transportation
1984: Member of the Institution of Materials, Minerals and Mining
1984: Chartered Engineer
1990: Fellow of the Chartered Institution of Highways and Transportation

Experience in Forensic Investigations and Expert Witness/Advisor Role:

Forty years experience in engineering geology and soil mechanics including a wide variety of forensic investigation into soil/structure failures and impending failures. Twenty five years experience as an expert witness/advisor including as an expert at adjudications and in the Technology and Construction Court.

Airport and Frontier Access Road Tunnel, Gibraltar
Expert witness in a dispute related to the termination of a contract for the construction of the project. Advice and evidence on the reliability of ground investigation information in weak siltstone/mudstone rock and thereby the foreseeability of encountering ground that could not be excavated with a clamshell grab during the construction of diaphragm walls forming the tunnel side and central support walls. Attendance at expert meetings. Expert evidence given in the Technology and Construction Court.

Ipswich Sewer Tunnel, Suffolk, UK

Examination of repeated failure of the construction of an access shaft and the failed remedial measures. Presentation of evidence at adjudication into failures.

DTSS Contract 6, Singapore

Geotechnical support to external expert witness appointed by Singapore contractor examining causation of a major roof collapse of tunnelling machine launch chamber at 45m depth. Reviewing expert reports produced by experts appointed by client body for arbitration and assisting in formulation of rebuttal report.

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expert witness and advisory services

Railway cut and cover tunnel, Hertfordshire, England
Expert adviser to construction contractor's insurers on a major collapse of the concrete pinned arch tunnel structure over a mainline railway being built to allow development of a superstore and car park over the railway. Advice reports and attendance at expert meeting.

Major 4 lane Highway, Hertfordshire, England
Expert advisor and witness with regard to the sudden development of substantial heave below the highway pavement with lime stabilised clays as the sub-base. Attendance at mediations, expert meeting and preparation of an expert witness report.

Cement Works, Vietnam

Geotechnical advisor for insurers into the review of the claimed slope failure of eighteen metre high earthworks on soft ground causing shearing of the piled foundations to the cement works buildings by lateral displacement. Expert advice report prepared into causation of the damage and the liability of various parties involved in the design and construction of the works.

Port workers dormitory complex and client guesthouse, Oman

Expert advisor and witness with regard to the severe heave damage to the whole complex. Attendance and Powerpoint presentation of issues at arbitration. Arbitration postponed due to counsel's sudden illness. Cross examination awaited.

Sinkhole on residential development, Hertfordshire, England

Expert advise on the cause of the sinkhole development, associated underground mining, planned remedial works and future residual risks.

Major DBFO Highway scheme, North East England

Geotechnical and geological advice to expert advising PII insurers on cause of almost immediate pavement failure on opening of the scheme.

Airport, Scotland

Expert advisor into repeated severe distortion and collapse of runway apron pavements caused by movement of material, within the underlying coastal reclamation earthworks built to extend the runway. Expert report for adjudication, attendance at adjudication hearing for cross examination.

Major Highway, Luton, England

Expert advice to CAR insurers on the stability of earthworks of a widened reinforced soil embankment.

Major DBFO Highway scheme, East of England

One of two expert advisors to CAR insurers on cause of premature pavement failures on the 8 lane highway.

Navigation Point, Castleford, England

Expert advice and report on gasworks waste contamination of a 1337 unit residential development site on alluvial soil adjacent to a major river, including expert meetings and giving expert evidence in the Technology and Construction Court.

Major Excavation, Dubai

Expert advisor and witness in a dispute under DIAC rules with respect to the assessment and foreseeability of rock conditions in a 60m deep earthworks excavation. Expert report prepared and expert meetings attended.

Anerley Road, Penge, London

Expert advisor and witness on a case involving unauthorised removal by a third party of a large lime tree adjacent to a recently extended Victorian property. Expert advice and expert reports prepared reviewing the

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heave behaviour of the ground and property due to the tree removal. Attendance at expert meetings. Expert evidence given in the Technology and Construction Court.

Distribution Centre, Dartford

Expert advisor into the design of specialist ground support for the road pavement following settlement of part of the road pavement. Expert report prepared and attendance at expert meetings.

Freeport, Grand Bahamas – Phase 1

Examination of the design of the pavement and hurricane tie down anchors for ship to shore cranes followed pavement failure and determination of karstic (voided limestone) nature of ground. Supervised the ground investigation to inspect foundations and test the founding strata to the tie down anchors for competency to resist hurricane induced forces. Advice given on remedial measures

Major Petrochemical Plant Extensions, UAE

Expert advice with respect to a dispute over the foreseeability of soft and unsuitable ground conditions during the development of the base platform for a 350Ha extension.

Major Transport Infrastructure Project, East of England

Expert advisor in a multi faceted dispute with regard to the design and construction of the project. Advice given on the susceptibility of just under 2,000 spread foundations to the effects of tree roots induced heave and subsidence over the design life of the project.

Raising and Reclamation of Extensive Sabkha Areas, UAE

Expert advisor to Korean contractor on an EPC contract to review whether existing raising and reclamation of extensive sabkha areas complied with the stated specification requirements.

Deodar Road, Putney, London, England

Expert advice and expert reports into the impending failure of a section of brick and concrete river wall due to extensive ground raising by riparian owners. Reports detailed the historical instability of the wall before ground raising and established ground raising had accelerated substantial lateral and vertical displacement of the river wall. Attendance at expert meetings.

Rammed Earth Walls, London, England

Expert advice and witness reports on the deficiencies in material selection and construction of load bearing unstabilised rammed earth walls constructed as the external walls to a children's nursery for expert determination. Attendance at expert meetings and meetings with expert determiner.

Coastal cliff stability, Fairlight, Sussex, England

Expert geotechnical advisor with coastal engineering colleagues on the limitations and assumptions in the government cost benefit assessment for protecting the rock cliff toe to halt its rapid retreat. Advised on the unreliability of historic retreat rates due to site geology. Presented case to public open meeting with DEFRA consultants giving opposing view. Coastal protection scheme subsequently implemented.

Development site, Great Yarmouth, England

Expert advisor on the failure of surface and foul water sewers due to ground movements on a large residential development on deep soft ground. Review of remedial design measures and advice on the approach to re-design of infrastructure. Expert report and attendance at mediations and expert meetings.

Commercial building,Scarborough, England

Expert advice and report on the failure of a sheet pile retaining wall to retain residential gardens on a major extension of a former museum on a steep valley in Scarborough. Attendance at mediation.

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A12 Capel St Mary, Suffolk, England – Crib Wall Failure

Geotechnical director for the evaluation of the failure mechanism and remedial measures for a major crib wall failure on a large Highways Agency project. The project included an extensive length of concrete crib walling to retain an existing road above a new slip road to the A12. Catastrophic failure of a 20-30m length occurred and investigations indicated extensive internal failure of the crib units. Reports were prepared highlighting causation was related to the weakness of the British Standard Code of Practice in the analysis of such structures. Research into world-wide design codes and papers on crib wall design.

Major Landfill Odour Incident, Essex, England

Expert report for the Environment Agency in contemplation of a criminal prosecution of a major commercial landfill operator under the 1990 Environmental Protection Act for extensive air pollution incidents over a period of many months. The report reviewed the operational management and landfilling practice of the site over its considerable lifetime and in particular in the period leading up to the pollution incidents at one of the United Kingdom's largest former co-disposal landfill.

Warehouse, Tilbury, Essex, England

Expert advisor in relation to severe differential settlement of warehouse floor surrounding pavements, punching failure of piles of former structures through the warehouse floor and effects on these issues on piled foundations to superstructure. Review of design competency, expert advice report on projected future settlement and defects that have, or will occur, with continued settlement including health and safety risks associated with failed gas protection measures. Advice on potential remedial measures.

Grimsby Fish Docks, Lincolnshire, England

Investigation and assessment of the effects of unexpected high settlements on the piles for a new fish market building constructed upon a reclaimed section of the existing dock basin.

Cobbolds Point, Felixstowe, Suffolk, England

Expert witness for catastrophic failure of privately owned timber piled seawall which collapsed into new coastal engineering works after storm. Work included review of design of remedial works and the production of expert advice and expert reports. Attendance at mediation.

Stanley Reservoir, Stafford, England

Investigation of a Victorian dam with a vertical toe masonry wall to evaluate the slope stability under static and quasi-dynamic (earthquake) loading. The dam overtopped in the 1930's and led to near collapse. No record drawing of its construction or remedial measures existed. An investigation of the dam, its masonry toe wall, slope stability and other analyse were undertaken to examine stability with a new spillway structure. Instrumentation examined the response of water levels in and under the dam to changes in reservoir level.

Coastal defence, North Norfolk, England

Expert advisor/witness on a case involving the slope failure of an earth revetment coastal defence structure as a result of wave action. Expert report prepared and attendance at expert meetings.

The Dip, Felixstowe, Suffolk, England

Geotechnical advisor into the catastrophic failure of 150m length of timber piled mass concrete seawall after a major storm. Investigation into the stability of 1.5km of remaining seawall and clay cliffs was undertaken. Reports revealed a history of sea wall failures due to both toe erosion and over-steep coastal cliffs.

Calvert Landfill Site, Buckinghamshire, England

Expert report and giving evidence including cross examination at Planning Inspectorate inquiry into the non determination by the Environment Agency of an application to retain an unlicensed composting facility on a completed landfill cell.

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Specialist Experience in Tunnelling:
Thirty years experience with extensive involvement in the design, supervision and/or interpretation of ground investigations for micro and large scale tunnels in soft ground and weak rock in the United Kingdom and the Far East.

Singapore MRT East West Line, Contracts 704, 705 and 708
Geotechnical evaluation of ground investigation information for the tender designs of the running tunnels on three contracts for the above project including assessment of the potential variation of design parameters from the client's defined parameters in the tender documents.

Singapore DTSS Tunnels
Preparation of preliminary geotechnical interpretative reports for contracts 1, 2, 3 and 4 tenders outlining the recommended tunnelling methods, rate of tunnelling, shaft and associated works recommended construction methods. Design of additional ground investigation and preparation of final geotechnical interpretative reports for the tunnels and shafts on contract 1, Changi Tunnel. Support geotechnical engineer to external expert witness on claim for unforeseen ground conditions on contract 6.

Jubilee Line Waterloo to London Bridge, London, UK
Geotechnical engineer involved in the interpretation of the ground investigation for the running tunnels directly beneath the Railtrack viaducts between Waterloo East and London Bridge to permit detailed assessment of the potential settlement induced by tunnelling and the design of the tunnel lining.

Crossrail – Farringdon Station, London, UK
Geotechnical engineer in the interpretation of the ground investigation for the running tunnels and a large deep service box excavation underneath the present London Underground station and adjacent buildings. The ground conditions showed substantial variation in the level of strata and ground water conditions indicative of a major geological unconformity. Additional investigation was designed to permit the evaluation of the effect of the unconformity on design of the tunnels.

Coldrife Lake Stream Diversion Tunnel, Northumberland, UK
Design and interpretation of the ground investigation for a 3m diameter stream diversion tunnel through faulted coal measures to provide a water supply to a new lake formed upon opencast backfill with inadequate surface water input.

Burnham on Sea Sewerage Scheme Phase 4C, Somerset, UK.
Project geotechnical engineer for the 1.2m pipejacked microtunnel required to pass diagonally beneath the town centre comprising Victorian buildings built upon thin dune sands over deep soft alluvium. Advanced techniques were utilised to examine deformation characteristics to evaluate potential ground losses and angular distortion induced on buildings by tunnelling. The investigation also examined means of minimising settlement when constructing shafts between properties. Assistance in the design and specification of ground improvement techniques at shafts, drive and reception shafts. Design and specification of the project's ground instrumentation.

Project Orwell, Ipswich, Suffolk, England
Geotechnical project manager for the desk study and design of investigation for 3 major storage tanks and shallow connecting tunnels for phase 1 of the project. Geotechnical director for the desk study, preliminary ground investigation and interpretation of the ground investigation for a 5.5km tunnel up to 55m deep crossing the residential and port area of Ipswich including 12 shafts. Ground conditions comprised weathered and solutioned chalk with infilled, vertically sided, buried channels and locally contaminated ground. Assistance on the NEC Storage Tanks contract in the assessment of variations in ground conditions arising from compensation events varying the line/level of the tanks and connecting tunnels.

Dartford Cable Tunnel, England
Design of geotechnical/geoenvironmental investigation for 3m diameter tunnel running under the River Thames including UXB investigations and geophysical investigations for solution cavities in chalk. Assistance to tunnelling contractors and client organisations on geotechnical aspects of claims for unexpected ground conditions.

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Specialist experience in infrastructure earthworks, slopes, pavements and foundations:

Forty years experience in site investigation, specification and design of earthworks, slopes and pavements foundations for major infrastructure projects in the United Kingdom, North and West Africa, Gulf region and South East Asia including contractual management or advice on investigation and construction contracts.

United Kingdom Highways

Engineering geologist and geotechnical project manager/director for earthworks,slopes and structural foundations advice including site and ground investigations, specification and design on over 20 major highway projects with a combined length in excess of 300km and construction value over £1bn. The investigations included a wide range of techniques, with trial pits and trenches up to 40m long and 7m deep in landslipped ground. The earthworks included design and specification of embankments over former landslips, old landfills, deep recent soft alluvium, made ground and around structures including Armco arch culverts. Cutting design and assessments included the evaluation of acceptability for reuse as natural or stabilised materials, mitigation of gas release in old landfills and stabilisation of existing landslips. Assistance with pavement design in providing input aprpameters for subgrade and assessment of potential unbound subbase materials. Foundation design included a wide range of piled, raft and spread foundations. Extensive design and reporting on the results of ground instrumentation into ground movements and piling induced vibrations for a wide variety of earthworks and structures undertaken and the preparation of detailed feedback reports on construction. Design included the use of innovative techniques included expanded polystyrene fill on five projects to reduce structural loads and accelerate construction together with preparation of research papers on its design, specification and construction. Investigation and design into widening of MI Junction 6A-10 and alternative designs for Second Severn Crossing, Avon Approach Roads. Forensic investigation and reporting of a crib wall failure on the A12 Capel St Mary Bypass, Suffolk.

United Kingdom Railways

Geotechnical project director for the investigation and remedial design of existing earthwork slopes and structures for London Underground Limited, Railtrack, Network Rail and private companies. Detailed desk studies, investigation and remedial work outline design were prepared for fifteen sites on Northern, Central, District and Piccadilly lines including the emergency work remedial design for an embankment. Detailed design and design review for various embankment and cutting remedial works including the use of traditional and lime piles for Railtrack. Category 3 check of piled embankment on A120 Dovercourt Bypass and for the UK's first expanded polystyrene railway embankment replacing an existing structure over an infilled river channel. Design input on use of polystyrene fill for emergency rebuilding of a failed railway embankment in Ireland. Review of earthwork issues during the construction of a new rail link to Felixstowe Docks.

Other United Kingdom Earthworks

Design of earthworks and slopes for Thames Flood Bank Raising Contracts 14 and 26, investigation and earthworks design and/or assessment of the reclamation earthworks and slopes for port extensions at Grimsby, Felixstowe and Tilbury and general reclamation at Cattedown, Plymouth. Designs involved extensive use of ground improvement, staged construction and hydraulic filling. Design of earthworks and slopes on peat for the construction of oil interception facilities at BP Llandarcy.

Overseas Highways:

Libya

Geological/geotechnical mapping, ground investigations and earthworks design for new rural roads in coastal sabkhah, inland mountain and wadi areas.

Oman

Earthworks design for new cross-country roads within major wadis. Including the design of rock cuttings, reinforced earth walls and the reuse of coarse wadi infill deposits as structural fill.

Nigeria

Ground investigations and earthworks design for new urban roads in Lagos, Nigeria including evaluation of potential imported construction materials.

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Specialist Experience in Ports and Harbours:

Over 25 years experience in geotechnical investigation, design and construction of new and improved port and harbour facilities. Contractual management of on onshore and offshore ground investigation contracts.

Port of Felixstowe, Suffolk, UK – Trinity 3 Terminal

Client's geotechnical advisor for 900m of new quay wall and container stacking facilities on marshland and estuarine mud flats overlying chalk. Geotechnical desk study, assessment and monitoring of construction tenderers' investigation for the works, review of tenderers' outline design proposals, contractor's detailed design proposals and assessment of monitoring data in relation to long term settlement criteria for the works.

Tilbury Riverside Extension, Essex, UK

Site investigation of the tidal flats and river bed for major reclamation to from a new deep water berth and container storage facility. Design advisor and checker for the geotechnical team on the design of the reclamation and monitoring works for the contractor, Amec. Assessment of reclamation monitoring and adviser to Amec on managing and controlling the sub-contractor works during reclamation.

Freeport, Grand Bahamas – Phase 1

Review of design and construction of quay wall, ship to shore crane rail foundations and hurricane tie down anchor blocks for ship to shore cranes after pavement defects in container stacking related to underlying karstic limestone.

Freeport, Grand Bahamas – Phase 2

Review of ground investigation on karstic limestone for the determination of design options for the stabilisation/infilling of karstic features underlying the container stacking areas, crane rail foundations, hurricane tie down anchor blocks including detailed risk assessment of these options and 'do nothing' option. Assessment of effects on quay wall piling and of the piling on the cross island tidal ground water movements.

Grimsby Fish Docks, Lincolnshire, UK

Desk study, ground investigation design, supervision and assessment for new fish quay within existing dock including reclamation of part of the existing dock basin. Geotechnical design of new facility, review of ongoing reclamation works and assessment of post construction settlements against predicted performance.

Port of Felixstowe, Suffolk, UK – Felixstowe South Reconfiguration

Detailed desk study, design and supervision of marine and land ground investigations for scheme to allow design by tendering contractors. Scheme includes 1500m of new deep water quay wall, realigned Harwich Haven navigation channel, reclamation of existing Landguard berths area, demolition of existing berth and other facilities including Victorian basin and chemical storage tank farm. Advice to client on reuse of dredgings and other geotechnical matters for planning inquiry and environmental assessment. Investigation and assessment of major localised anomaly in chalk associated with solutioning of the limestone.

Barry Harbour, Wales, UK

Desk study, design and supervision of marine ground investigation for conversion of harbour into major marina facility. Assessment of ground conditions on engineering requirements to reclaim nearshore beach areas, construction of tidal barrier and lock gate facilities and new buildings on reclaimed areas.

Port of Felixstowe, Suffolk, UK – Landguard Terminal

Site investigation of the pavement area for container stacking and handling equipment and determination of the causes of the pavement deficiencies. Geotechnical design related to remedial works and project management of the remedial works contract.

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Employment history

Capita May 2007 onwards

Director

Expert advisor/witness for CAR, PII and domestic insurance claims and contractual and technical disputes on construction and building projects in the UK, Europe and Middle East. Review of NEC3 and GCWorks contracts for London Development Agency and Her Majesty's Customs and Excise. Preparation of revised construction contract Benina Airport, Benghazi, Libya. Design reviewer for landfill cells at St Helier, Jersey.

Babtie Group and latterly Jacobs Babtie 1990 - April 2007

Divisional Director,

Director managing up to 200 staff with direct involvement in undertaking a variety of projects worldwide including site investigations, materials assessment, geotechnical design, forensic engineering studies, hydrogeology, mining, geotechnical risk assessment, environmental studies and waste engineering. Particular technical expertise includes ground investigations, earthworks and foundation engineering, slope stability, landfill design. Directed redevelopment of major USAF airbase to form a new village. Contract management on construction contracts in UK and Slovakia. Expert witness/advisor for litigation, insurance, planning appeal cases for structural movements and failures for construction projects including earth build structures, coastal defences and waste projects. Earthworks expertise includes investigation and design of new/remedial earthworks and slopes for highways, railways, tunnels, ports, cliffs and reclamation sites for housing and commercial development on soft ground. Projects include MRT and DTSS tunnels and shafts, Singapore, 2000Ha reclamation Jakarta, Indonesia, earth slopes for London Underground and Network Rail.

Dobbie and Partners 1974 - 1990

Junior Engineer to Associate Partner,

Projects in the UK, West Africa and Middle East including soft ground tunnels, dams, major highway earthworks, slopes and foundations, tidal and non tidal defences, reinforced embankments and ultra lightweight embankments, remedial works for slope and cliff failures, residential, industrial and heavy commercial foundation. Prepared research reports for TRL on A12 Great Yarmouth Western Bypass. Expert witness at arbitration with respect to drainage trench excavations in Norfolk.

Appointments:

East Anglian Branch, Institution of Highways and Transportation
Secretary 1986-1989

Institution of Civil Engineers Site Investigation Steering Group Working Panel Three – Procurement
Member 1991-1993

Committee C12 Earthworks Drainage & Subgrade Permanent International Association of Road Congresses UK Member 1994-1996

Technical papers:

Co-author and author of seven technical papers including state of the art papers in polystyrene fill design and construction. Some specific papers are detailed below:-

Design of reinforced embankments for Great Yarmouth Bypass (with D Williams) Proc 11th Int. Conference on Soil Mechanics and Foundation Engineering, San Francisco, USA pp 1811-1814 1985

Geotechnical investigation, design and construction on soft compressible soils. Sino-British Highways and Urban Conference, Beijing, China pp 171-182 1986

Polystyrene as an ultra lightweight engineered fill. Engineered Fills, Newcastle, UK Thomas Telford pp 281-301 1993

United Kingdom Design and Construction Experience with EPS, Tokyo, Japan. EPS Tokyo '96 EDO Japan pp 236-246 1996

APPENDIX B – INVESTIGATION A TABLES

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Investigation A, Stiffness Characterisation
Summary of Approximate Permissible Foundation Movements to Maintain a Minimum 20kN Reaction at the End Bearings

Location	Test	Represents	Average Load/mm reduction to end jacks [kN/mm]	$\delta_{permissible}$ to maintain 20kN reaction (Assuming 33kN reaction at start) from site tests [mm]	$\delta_{permissible}$ to maintain 20kN reaction (Assuming 33kN reaction at start) from Robot computer analysis model [mm]	Comment
2_1	Jacks 3 and 4 Raised in unison	Heave at middle foundation	3.0	**4.3**	2.0	Site test had no vehicle present. Computer model includes mass of bus. Site measured values should therefore be reduced (because of lower initial reactions at one end and the effects of movement being focussed at this end).
3	Jacks 3 and 4 Raised in unison		3.0	**4.3**		
3	Jacks 3 and 4 Raised in unison, repeat		2.3	**5.7**		
2_2	Jacks 1 and 2 raised, following lowering, in unison (gritter)	Settlement of end foundation	2.0	**6.5**	4.0	Guideway appears to be less stiff (some cracking) than that allowed for within computer model. Model has adopted the maximum code value of E_c (34kN/mm^2) for the 50N/mm^2 concrete specified. Full uncracked I value also taken (8.7x10^{9}mm^4)
3	Jacks 1 and 2 raised, following lowering, in unison (gritter)		2.1	**6.2**		
2_1	End Jacks 1, 2, 5 and 6 Raised in turn	Transverse differential foundation settlement	7.1	**1.8**	0.8	Spacer beam connected to guideway beam with full fixity (no allowance for rotation to occur) in computer model. Some movement / rotation probably occurring in reality.
3	End Jacks 1, 2, 5 and 6 Raised in turn		5.8	**2.2**		
2_1	Central Jacks 3 and 4 Raised in turn	Heave / transverse differential foundation movement at middle foundation	7.0	**1.9**		Site values comparable with computer analyses for symmetrical heave.
3	Central Jacks 3 and 4 Raised in turn		5.4	**2.4**		

CGB, Investigation A, Location 2_1 - Displacements / Deflections (Symmetric, No gritter)

Comments	Actual Jack Displacements						Reactions (Jack Loads and Changes)							Differences from Datum				
	Jack 1	Jack 2	Jack 3	Jack 4	Jack 5	Jack 6		Jack 1	Jack 2	Jack 3	Jack 4	Jack 5	Jack 6	Jack at which change is being considered	Differential displacement between loaded jack and opposite, adjacent jack when at ends or loaded jack when at centre.	Change in load on jack(s) being considered	Change in load per mm at jack being considered.	
	LLH20111	LLH200201	LLH20114	LLH201114 (To 01:00hrs) LLH201123 (From 01:00 hrs)	LLH20113	LH20115												
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]		[kN]	[kN]	[kN]	[kN]	[kN]	[kN]		[mm]	[kN]	[kN/mm]	
Strainstall advise jacks and sensors brought back down to 0mm. Used as datum.	0.00	0.00	0.00	0.00	0.00	0.00		31.5	17.2	97.0	89.4	15.9	52.4					
Jacks 1 & 2, raised towards 7.2mm	7.18	7.10	1.22	1.23	-0.31	-0.44	Recorded	41.5	27.8	81.6	73.4	18.5	55.4	Jack 1	7.18	10.0	**1.4**	Jack 1 with respect to Jack 1 and relative to Jack 1.
							Change	10.0	10.6	-15.4	-16.0	2.6	3.0	Jack 2	7.10	10.6	**1.5**	Jack 2 with respect to Jack 2 and relative to Jack 2.
Jacks 3 & 4, raised towards 3.5mm	0.66	1.01	3.14	3.48	0.57	0.72	Recorded	24.1	10.0	114.0	116.2	12.6	39.7	Jack 1	-2.48	-7.4	**3.0**	Jack 1 with respect to Jack 3 and relative to Jack 3.
														Jack 2	-2.48	-7.2	**2.9**	Jack 2 with respect to Jack 4 and relative to Jack 4.
							Change	-7.4	-7.2	17.0	26.7	-3.3	-12.7	Jack 5	-2.57	-3.3	**1.3**	Jack 5 with respect to Jack 3 and relative to Jack 3.
														Jack 6	-2.76	-12.7	**4.6**	Jack 6 with respect to Jack 4 and relative to Jack 4.
Jacks 5 & 6, raised towards 17mm	-1.71	-2.21	1.96	0.86	17.08	15.53	Recorded	43.3	40.3	59.5	57.2	45.4	62.4	Jack 5	17.08	29.5	**1.7**	Jack 5 with respect to Jack 5 and relative to Jack 5.
							Change	11.8	23.1	-37.6	-32.2	29.5	10.0	Jack 6	15.53	10.0	**0.6**	Jack 6 with repsect to Jack 6 and relative to Jack 6.

CGB, Investigation A, Location 2_1 - Displacements / Deflections (Asymmetric, No gritter)																			
Comments	"Actual" Jack Displacements [mm]						Reactions							Differences from datum					
	Jack 1	Jack 2	Jack 3	Jack 4	Jack 5	Jack 6													
	LLH20111	LLH200201	LLH20114	LLH201114	LLH20113	LH20115		Jack 1	Jack 2	Jack 3	Jack 4	Jack 5	Jack 6	Jack at which change is being considered.	Differential displacement between loaded jack and opposite, adjacent jack at ends or loaded jack when at centre.	Change in load at jack(s) being considered.	Change in load per mm at jack being considered.		
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]		[kN]	[kN]	[kN]	[kN]	[kN]	[kN]		[mm]	[kN]	[kN/mm]		
Used as datum	0.00	0.00	0.00	0.00	0.00	0.00	Datum	31.5	17.2	97.0	89.4	15.9	52.4						
Jack 1 raised to around +6.49mm.	6.49	4.62	1.32	0.87	0.11	-0.47	Recorded	60.6	1.4	68.4	99.1	19.7	55.9	Jack 2	-1.86	-15.8	8.5	Jack 2 with respect to Jack 1and relative to Jack 1.	
							Change	29.1	-15.8	-28.6	9.7	3.8	3.5						
Jack 2 raised to around +6.27mm.	3.36	6.27	0.27	1.98	0.19	0.64	Recorded	10.3	53.3	95.9	70.0	25.4	35.6	Jack 1	-2.91	-21.3	7.3	Jack 1 with respect to Jack 2 and relative to Jack 2.	
							Change	-21.3	36.1	-1.1	-19.4	9.5	-16.9						
Jack 3 raised to around +6.66mm.	2.56	0.09	6.66	3.11	3.94	1.18	Recorded	6.2	25.8	150.6	83.1	1.5	47.2	Jack 1	-4.10	-25.4	6.2	Jack 1with respect to Jack 3 and relative to Jack 3.	
							Change	-25.4	8.6	53.6	-6.3	-14.4	-5.2	Jack 5	-2.72	-14.4	5.3	Jack 5 with respect to Jack 3 and relative to Jack 3.	
Jack 4(b) raised to around +8.24mm.	1.65	5.57	3.21	8.24	1.38	3.50	Recorded	31.5	0.0	71.1	152.1	18.7	3.9	Jack 2	-2.67	-17.2	6.5	Jack 2 with respect to Jack 4 and relative to Jack 4.	
							Change	0.0	-17.2	-25.9	62.6	2.8	-48.5	Jack 6	-4.74	-48.5	10.2	Jack 6 with respect to Jack 4 and relative to Jack 4.	
Jack 5 raised to around +9.8mm.	-0.51	-1.30	1.49	0.62	9.80	5.21	Recorded	27.9	35.0	56.2	109.1	66.5	11.7	Jack 6	-4.59	-40.8	8.9	Jack 6 with respect to Jack 5 and relative to Jack 5.	
							Change	-3.6	17.8	-40.8	19.7	50.6	-40.8						
Jack 6 raised to around +6.94mm.	-1.25	0.18	-0.18	1.74	3.73	6.94	Recorded	45.1	11.9	96.2	72.6	3.6	74.3	Jack 5	-3.21	-12.3	3.8	Jack 5 with respect to Jack 6 and relative to Jack 6.	
							Change	13.6	-5.3	-0.8	-16.9	-12.3	21.9						

CGB, Investigation A, Location 2_2 - Displacements / Deflections (Symmetric, Static Gritter)

Comments	Actual Jack Displacements				Reactions (Jack Loads and Changes)												Differences from Datum			
	Jack 1	Jack 2	Jack 5	Jack 6 (NB These readings are suspect, Jack possibly at bottom of travel)	Jack-01 LLH20115			Jack-02 LLH20113			Jack-05 LLH200201			Jack-06 LLH20114 (NB These readings are suspect, jack seems to reach bottom of travel)			Jack at which change is being considered	Displacement at loaded jack.	Change in load on jack(s) being considered.	Change in load per mm at jack being considered.	
						Recorded	Change		Recorded	Change		Recorded	Change		Recorded	Change					
	[mm]	[mm]	[mm]	[mm]	[Bar]	[kN]	[kN]	[Bar]	[kN]	[kN]	[Bar]	[kN]	[kN]	[Bar]	[kN]	[kN]		[mm]	[kN]	[kN/mm]	
USED AS DATUM	0.00	0.00	0.00	0.00	79.27	21.94	0.00	160.92	41.03	0.00	142.58	39.44	0.00	109.58	29.46	0.00					
Gritter static / parked on guideway	0.33	0.30	-1.83	-1.54	68.24	18.89	-3.06	147.56	37.69	-3.33	217.63	60.28	20.83	167.71	45.14	15.68					
Symmetric Jacks 1& 2 lowered towards -8.0mm **NB** These results are suspect. Both Jacks 1 and 2 may have "bottomed out".	-6.26	-7.79	-1.38	-1.36	-0.28	0.00	-21.94	-0.28	0.00	-41.03	192.25	53.33	13.89	165.47	44.59	15.14	Jack 1	-6.26	-21.94	**3.51**	Jack 1 with respect to Jack 1 and relative to Jack 1.
																	Jack 2	-7.79	-41.03	**5.27**	Jack 2 with respect to Jack 2 and relative to Jack 2.
Symmetric Jacks 1& 2 lowered towards -5.0mm	-4.66	-4.90	-1.53	-1.44	48.80	13.33	-8.61	118.11	30.26	-10.77	201.46	55.83	16.39	165.46	44.59	15.14	Jack 1	-4.66	-8.61	**1.85**	Jack 1 with respect to Jack 1 and relative to Jack 1.
																	Jack 2	-4.90	-10.77	**2.20**	Jack 2 with respect to Jack 2 and relative to Jack 2.
Symmetric Jacks 1& 2 raised towards +3.75mm	3.59	3.42	-2.02	-1.59	95.02	26.39	4.44	305.32	79.73	38.70	224.20	62.22	22.78	166.14	44.86	15.41	Jack 1	3.59	4.44	**1.24**	Jack 1 with respect to Jack 1 and relative to Jack 1.
																	Jack 2	3.42	38.70	**11.31**	Jack 2 with respect to Jack 2 and relative to Jack 2.
Symmetric Jacks 1& 2 raised towards +8.0mm	6.96	6.76	-2.31	-1.67	118.09	32.78	10.83	271.00	70.54	29.51	234.65	65.00	25.56	165.64	44.59	15.14	Jack 1	6.96	10.83	**1.56**	Jack 1 with respect to Jack 1 and relative to Jack 1.
																	Jack 2	6.76	29.51	**4.37**	Jack 2 with respect to Jack 2 and relative to Jack 2.

CGB, Investigation A, Location 3 - Displacements / Deflections (Symmetric, Gritter present)

Comments	Actual Jack Displacement						Reactions (Jack Loads and Changes)							Differences from Datum				
	Jack 1	Jack 2	Elastomeric Bearings		Jack 5	Jack 6		Jack 1	Jack 2	Elastomeric Bearings		Jack 5	Jack 6	Jack at which change is being considered	Vertical displacement at jack(s) being raised	Change in load on jack(s) being considered	**Change in load per mm at jack being considered**	
	LLH20114	LLH20111			LLH201123	LLH200201		LLH20114	LLH20111			LLH201123	LLH200201					
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]		[kN]	[kN]	[kN]	[kN]	[kN]	[kN]		[mm]	[kN]	**[kN/mm]**	
Datum	0.00	0.00	0.00	0.00	0.00	0.00		20.54	31.79			16.56	43.61					
Jacks 1 & 2 @ nom +7.3mm Including gritter	7.38	7.31	-0.10	-0.10	-2.44	-2.18	Recorded	29.73	38.72			41.88	66.11	Jack 1	7.38	9.19	**1.2**	Jack 1 with respect to Jack 1
							Change	9.19	6.92			25.31	22.50	Jack 2	7.31	6.92	**0.9**	Jack 2 with respect to Jack 2
Jacks 1 & 2 @ nom -2.5mm Including gritter **NB** May not be robust data, jacks 1 and 2 possibly in excess of stroke.	-2.47	-2.88	-0.26	-0.08	-2.03	-1.95	Recorded	5.41	14.36			34.38	64.44	Jack 1	-2.47	-15.14	**6.1**	Jack 1 with respect to Jack 1
							Change	-15.14	-17.44			17.81	20.83	Jack 2	-2.88	-17.44	**6.1**	Jack 2 with respect to Jack 2
Jacks 1 & 2 @ nom -1.5 Including gritter **NB** Re-distribution of load on jacks 1 and 2, following lowering and reaching bottom of stroke, results in redistribution of load as jacks are re-raised.	-1.31	-1.93	-0.28	-0.06	-2.03	-1.95	Recorded	23.51	19.23			34.38	64.44	Jack 1	-1.31	2.97	**-2.3**	Jack 1 with respect to Jack 1
							Change	2.97	-12.56			17.81	20.83	Jack 2	-1.93	-12.56	**6.5**	Jack 2 with respect to Jack 2

CGB, Investigation A, Location 3 - Displacements / Deflections (Symmetric, No Gritter)

Comments	Actual Jack Displacement						Reactions (Jack Loads and Changes)					Differences from Datum				
	Jack 1	Jack 2	Jack3	Jack 4	Jack 5	Jack 6										
Jacks 1 & 2 @ end ch 7333 Jacks 5 & 6 @ and ch 7348	LLH20114	LLH20111	LLH20113	LLH201114	LLH201123	LLH200201		Jack 1	Jack 2	Jack 5	Jack 6	Jack at which change is being considered	Differential displacement between loaded jack and opposite, adjacent jack at ends or loaded jack when at centre.	Change in load on jack(s) being considered.	Change in load per mm at jack being considered.	
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]		[kN]	[kN]	[kN]	[kN]		[mm]	[kN]	[kN/mm]	
Taken as datum for start of symmetric testing	0.00	0.00	0.00	0.00	0.00	0.00	Datum	27.6	22.8	23.1	40.6					
Jacks 1 & 2 (End) raised towards +7.5mm	7.44	7.55	0.65	0.71	-0.72	-0.73	Recorded	36.2	35.1	32.2	48.3	Jack 1	7.44	8.6	**1.2**	Jack 1 with respect to Jack 1 and relative to Jack 1.
							Change	8.6	12.3	9.1	7.8	Jack 2	7.55	12.3	**1.6**	Jack 2with respect to Jack 2 and relative to Jack 2.
Jacks 3 & 4 ("Centre") raised towards +5.5mm, "peak"	1.62	1.82	5.32	5.57	1.25	1.21	Recorded	12.4	12.1	13.8	29.2	Jack 1	-3.70	-15.1	**4.1**	Jack 1 with respect to Jack 3 and relative to Jack 3.
												Jack 2	-3.75	-10.8	**2.9**	Jack 2 with respect to Jack 4 and relative to Jack 4.
							Change	-15.1	-10.8	-9.4	-11.4	Jack5	-4.07	-9.4	**2.3**	Jack 5 with respect to Jack 3 and relative to Jack 3.
												Jack 6	-4.37	-11.4	**2.6**	Jack 6 with respect to Jack 4 and relative to Jack 4.
Jacks 5 & 6 (End) raised towards +5.9mm	-0.60	-0.60	0.81	0.45	5.84	5.89	Recorded	29.2	30.3	31.3	48.6	Jack 5	5.84	8.1	**1.4**	Jack 5 with respect to Jack 5 and relative to Jack 5.
							Change	1.6	7.4	8.1	8.1	Jack 6	5.89	8.1	**1.4**	Jack 6 with respect to Jack 6 and relative to Jack 6.

CGB, Investigation A, Location 3 - Displacements / Deflections (Asymmetric, no gritter)

Comments	Actual Jack Displacements						Reactions (Jack Loads and Changes)					Differences			
	Jack 1	Jack 2	Jack3	Jack 4	Jack 5	Jack 6									
	LLH20114	LLH20111	LLH20113	LLH201114	LLH201123	LLH200201		Jack 1	Jack 2	Jack 5	Jack 6	Jack at which change is being considered	Differential displacement between loaded jack and opposite, adjacent jack at ends or loaded jack when at centre	Change in load on jack(s) being considered	Change in load per mm at jack being considered
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]		[kN]	[kN]	[kN]	[kN]		[mm]	[kN]	[kN/mm]
Used as datum	0.00	0.00	0.00	0.00	0.00	0.00		23.2	23.6	17.5	45.3				
Jack 1 lowered to around -1.88mm. Not a formal test, obtained from recorded data during preparation for raising Jack 1.	-1.88	-1.01	-0.20	-0.12	0.03	0.10	Recorded	7.0	30.8	19.1	42.8	Jack 1	-0.87	-16.2	18.67 Jack 1 with respect to Jack 1 and relative to Jack 2.
							Change	-16.2	7.2	1.6	-2.5				
Jack 1 raised to around +7.8mm	7.80	3.90	0.63	0.37	-0.53	-0.94	Recorded	73.8	5.4	17.8	59.2	Jack 2	-3.91	-18.2	4.66 Jack 2 with respect to Jack 1 and relative to Jack 1.
							Change	50.5	-18.2	0.3	13.9				
Jack 2 lowered to around -2.55mm. Not a formal test, obtained from recorded data during preparation for raising Jack 2.	-1.22	-2.55	-0.24	-0.33	0.21	0.00	Recorded	32.4	4.1	14.4	45.8	Jack 2	-1.33	-19.5	14.68 Jack 2 with respect to Jack 2 and relative to Jack 1.
							Change	9.2	-19.5	-3.1	0.6				
Jack 2 raised to around +7.25mm.	3.95	7.25	0.58	0.94	-0.77	-0.31	Recorded	4.9	58.5	32.8	43.9	Jack 1	-3.30	-18.4	5.57 Jack 1 with respect to Jack 2 and relative to Jack 2.
							Change	-18.4	35.0	15.3	-1.4				
Jack 3 lowered to around -4.30mm. Not a formal test, obtained from recorded data during preparation for raising Jack 3.	-1.06	0.23	-4.30	-1.06	-1.27	-0.12	Recorded	39.5	20.0	36.9	40.3	Jack 3	-4.30	Unknown	
							Change	16.2	-3.6	19.4	-5.0				
Jack 3 raised to around +2.45mm.	1.11	0.32	2.45	0.68	0.81	0.02	Recorded	14.6	26.9	10.6	47.8	Jack 1	-1.35	-8.6	6.43 Jack 1 with respect to Jack 3 and relative to jack 3
							Change	-8.6	3.3	-6.9	2.5	Jack 5	-1.64	-6.9	4.18 Jack 5 with respect to Jack 3 and relative to Jack 3.
Jack 4 lowered to around -2.26mm. Not a formal test, obtained from recorded data during preparation for raising Jack 4.	0.13	-0.52	-0.62	-2.26	-0.01	-0.60	Recorded	22.2	33.6	17.2	53.9	Jack 4	-2.26	Unknown	
							Change	-1.1	10.0	-0.3	8.6				
Jack 4 raised to around +6.6mm.	0.85	3.24	1.43	6.60	-0.02	1.87	Recorded	27.8	3.8	29.7	20.6	Jack 2	-3.35	-19.7	5.89 Jack 2 with respect to Jack 4 and relative to Jack 4.
							Change	4.6	-19.7	12.2	-24.7	Jack 6	-4.72	-24.7	5.24 Jack 6 with respect to Jack 4 and relative to Jack 4.
Jack 5 lowered to around -2.88mm. Not a formal test, obtained from recorded data during preparation for raising Jack 5.	0.37	0.75	-0.28	-0.08	-2.88	-1.46	Recorded	24.6	19.7	0.9	55.3	Jack 5	-1.42	-16.6	11.67 Jack 5 with respect to Jack 5 and relative to Jack 6.
							Change	1.4	-3.8	-16.6	10.0				
Jack 5 raised to around +5.34mm.	-0.04	-0.49	0.18	0.16	5.34	2.62	Recorded	22.4	36.2	52.2	25.0	Jack 6	-2.72	-20.3	7.47 Jack 6 with respect to Jack 5 and relative to Jack 5.
							Change	-0.8	12.6	34.7	-20.3				
Jack 6 lowered to around -1.90mm. Not a formal test, obtained from recorded data during preparation for raising Jack6.	0.39	0.25	-0.19	-0.14	-0.92	-1.90	Recorded	20.8	25.9	26.3	31.9	Jack 6	-0.98	-13.3	13.67 Jack 6 with respect to Jack 6 and relative to Jack 5.
							Change	-2.4	2.3	8.8	-13.3				
Jack 6 raised to around +6.49mm.	-0.56	0.01	0.12	0.39	3.51	6.49	Recorded	35.7	23.8	1.6	76.7	Jack 5	-2.99	-15.9	5.34 Jack 5 with respect to Jack 6 and relative to Jack 6.
							Change	12.4	0.3	-15.9	31.4				

CGB, Investigation A, Location 3 - Displacements / Deflections (Repeat of Symmetric, No gritter)

Comments	**"Actual" Jack Displacements**						**Reactions (Jack Loads and Changes)**					**Differences from Datum**				
	Jack 1	**Jack 2**	**Jack 3**	**Jack 4**	**Jack 5**	**Jack 6**		**Jack 1**	**Jack 2**	**Jack 5**	**Jack 6**	Jack at which chnage is being considered	Differential vertical displacement at jack(s) being considered	Change in load on jack(s) being considered	**Change in load per mm at jack being considered**	
	LLH20114	LLH20111	LLH20113	LLH201114	LLH201123	LLH200201										
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]		[kN]	[kN]	[kN]	[kN]		[mm]	[kN]	**[kN/mm]**	
Datum							Datum	23.8	25.1	20.6	46.9					
Jacks 1&2 (end) towards +24mm	22.10	22.28	2.37	2.56	-2.05	-1.92	Recorded	53.0	59.3	44.7	70.6	Jack 1	22.10	29.2	**1.3**	Jack 1 with respect to Jack 1 and relative to Jack 1.
							Change	29.2	34.2	24.1	23.6	Jack 2	22.28	34.2	**1.5**	Jack 2 with respect to Jack 2 and relative to jack 2.
Jacks 3 & 4 ("centre") towards +9mm & +12mm respectively	3.24	4.04	8.85	12.08	2.41	2.91	Recorded	10.0	5.9	9.1	25.0	Jack 1	-5.60	-13.8	**2.5**	Jack 1 with respect to Jack 3 and relative to Jack 3.
												Jack 2	-8.04	-19.2	**2.4**	Jack 2 with respect to Jack 4 and relative to Jack 4.
							Change	-13.8	-19.2	-11.6	-21.9	Jack 5	-6.43	-11.6	**1.8**	Jack 5 with respect to Jack 3 and relative to Jack 3.
												Jack 6	-9.16	-21.9	**2.4**	Jack 6 with respect to Jack 4 and relative to Jack 4.

APPENDIX C – SHIM DISAPLACEMENT FROM INVESTIGATION B1 PHOTOGRAPHS

Blank for double-sided printing

INVESTIGATION B1 - SHIM MOVEMENT RELATIVE TO BEARING PAD

	Bearing N°	mm	Bearing N°	mm	Bearing N°	mm	Bearing N°	mm	Bearing N°	Comments
10946	1	0	2	0						Jan'14 photo incorrect for bearing 2
10946 - 10961	3	*	4	0	1	0	2	0		* Very large displacement - cannot estimate
10961 - 10976	3	*	4	15	1	0	2	0		* No shim at bearing 3
10976 - 10991	3	5	4	0	1	*	2	0		* Very large displacement - cannot estimate
10991 - 11006	3	0	4	0	1	2	2	0		cf alternate ends
11006 - 11021	3	0	4	3	1	0	2	0		
11021 - 11036	3	0	4	4	1	0	2	0		
11036 - 11051	3	0	4	0	1	0	2	0		Jan'14 photo incorrect for bearing 2
11051 - 11066	3	0	4	0	1	0	2	0		11.10.2015 photos for 3 and 4 should be transposed
11066 - 11081	3	0	4	2	1	0	2	2		
11081 - 11096	3	0	4	0	1	0	2	0		
11096 - 11111	3	6	4	0	1	2	2	2		
11111 - 11126	3	0	4	3 *	1	0	2	0		* Very large displacement - cannot estimate easily
11126 - 11141	3	0	4	0	1	0	2	0		

Blank for double-sided printing

APPENDIX D – JOINT DISPLACEMENT SUMMARIES BY ATKINS

Blank for double-sided printing

ATKINS

Atkins Limited

Your Ref:

Our Ref: 5047709/808/IH/L19762

BAM Nuttall Ltd
Cambridgeshire Guided Busway
4th Floor
80 New Bond Street
London
W1S 1SB

For the attention of Mr S Whalley, Project Manager

26 July 2016

Dear Sirs

Cambridgeshire Guided Busway

Defect Notification 287A - Bearing Displacements and Consequential Guideway Vertical Displacement

We write further to Defect 287A issued on 25 April 2014 to advise an increase in the number of non-compliant horizontal displacements since the issue of our original Defect Notice 287 on 16 October 2013.

Subsequent to the undertaking of Investigation C by Survey Solutions Ltd under the 'Guided Busway Testing and Investigative Contract' initiative between BAM and Cambridgeshire County Council, we were provided with a copy of those measurements and asked by the Employer to comment on apparent discrepancies between these measurements and the non-compliances list in our Defect Notice.

As a result of this request the Supervisor has undertaken a further survey, checking both the inner and the outer beams at each location identified in the Investigation C survey as exhibiting a beam displacement non-compliance in addition to undertaking a further check at each location identified in the 'Figure 1' attachment to the Defect 287A notification.

Our report in response to the Employer's request has been passed directly to Cambridgeshire County Council and its legal advisors.

The results of our check survey indicates a marked increase in the number of beam displacement non-compliances since the results of our July 2013 survey were reported in the original Defect Notice in 2013.

Defect 287 reported 109 non-compliances (at 106 separate chainages) measurements which exceeded the 2.0mm maximum vertical step tolerance. Our recent check survey has identified 343 such occurrences in excess of 2.0mm, those 343 not taking into account five locations counted in the original 287 notice where bearings have been subsequently reset and consequently not identified in later surveys.

Contd…

The results of the survey and audit are attached.

Yours faithfully

For and on behalf of Atkins Ltd

Ian Hodgkin
Supervisor

Enc Results of recent check survey

Cc Mr R Menzies – Cambridgeshire County Council – Service Director – Strategy and Development

DEFECT 287 VERTICAL GUIDEBEAM DISPLACEMENT

	T - to Camb	Physical measurements										
	F - from Camb	Survey Solutions Investigation C (mm)		DEF287 (Apr 2014)		12/05/2016		SS DEFECT		ADDITIONAL		
Chainage	S - single	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	Comments
1978	F		2.9				2.7		1			
2068	F	2.51				2.8		1				
2088	T	2.55				2.8		1				
2533	F	2.5						1				
2548	F	3						1				
2758	F		2.8				3.3		1			
3178	T				3		1.7					
3268	T	2.8				2.9		1				
3493	F		3.1				2.9		1			
3553	F		2.8				3.1		1			
3898	F				2	2.4	3.1			1	1	
3973	F	3				3.7		1				
4033	F	2	2.5			2.1	2.9	1	1			
4063	F	2.5				3		1				
4183	F		3.3				3.1		1			
4213	F		2.5				2.7		1			
4303	T	16.32	2.19	4		16.2	2.1	1	1			
4438	F	2.1	3			2.1	3.7	1	1			
4498	F		3.5				3.4		1			
5128	T				4	1.5	3.4				1	
5653	F		2.4				2.3		1			
5708	F	3.1				3.2	0	1				
5708	T	4.6	2.1			13.1	1.7	1	0			
5718	F	3.41	6.31		5			1	1			
5863	T		2.7				3.2		1			
5968	F				2	1.3	0					
5983	T	3.6	2.13	4				1	1			
5998	F		3.3				3.5		1			
6163	F		2.9				2.6		1			
6178	F		2.1				2.6		1			
6328	f	3.3	2.6			3.1	3	1	1			
6343	T	2.4	2.8		5	2.5	3.1	1	1			
6358	T			3		2.7				1		
6373	F		2.5				2.5		1			
6583	F		2.4				2.5		1			
6713	F	4.9	1	4				1				
6723	F			7		0						
6793	F	2.3				2.9		1				
6808	F		2.9				3.1		1			
6823	F		3				3		1			
6868	T		3				2.9		1			
7183	F	2.8	4.6			2.6	5	1	1			
7228	F		2.8				2.8		1			
7348	T		6.8				1.2		1			
7453	T	1.63	3.59		4				1			
7588	F		13.7				17		1			
7663	T		6.7				8.4		1			
7693	T		4				2.2		1			
7768	F	3				3		1				
7783	F		3.8				3.5		1			
7873	F	2.8				2.9	2.2	1			1	
7948	T	6.5				6.9		1				
7948	T		2.7				2.8		1			
7963	F	3.5				3.8		1				
7963	T	2.03				2.7		1				
7993	F				4	2.3	0			1		
7993	T	3.7				3.5		1				
8008	T	3.5				3.1		1				
8008	T		2.6				2.4		1			
8023	F		3				2.8		1			
8048	T	2.43		6		2.3		1				
8048	T		9.98		6		11		1			
8578	F	3.51	1.43	3				1				
8713	T	2.5				<2		0				
8728	F	2.4				2.4		1				
8728	F		2.5				2.9		1			
8863	F	0.11	1.14		4		<2					
8998	F				4		0					
9133	F		2.9				3.6		1			
9343	F		5.3				5.8		1			
9673	F		2.9				2.6		1			
9733	T				3		2.5				1	
9918												Longstanton junction
9996	F					2.9	4.1			1	1	
10015	F - HFS		7.3				8.7		1			
10030	T	2.3				3.4		1				
10045	T			3		3.3				1		
10120	F		3.2				3.3		1			
10195	F		3.5				3.5		1			
10240	T		2.1				2.6		1			
10255	F	2.2				2.7		1				
10270	T	4.6				4.8		1				Longstanton P&R
10465	F	3.7	2.8			5.2	4.3	1	1			

Defect 287

Page 1

		Physical measurements										
	T - to Camb F - from Camb	Survey Solutions Investigation C (mm)		DEF287 (Apr 2014)		12/05/2016		SS DEFECT		ADDITIONAL		
Chainage	S - single	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	Comments
10495	T		9.7				10.3		1			
11065	F	2.11	7.58		6			1	1			
11275	F			6		0						
11290	F		2.7				2.9		1			
11320	F	0.05	5.26		5		5.6		1			
11695	T	4.3				3.9		1				
11710	T			7		1.4						
11770	T	2.1				2.6		1				
11785	F	6.06	3.86		7	7.2	3	1	1			
11800	F		4.9				4.9		1			
11800	T	3.2				3.2		1				
11815	T	11.3	3.56	10		10.9	3.6	1	1			
11830	T		2.4				2.4		1			
11845	T	0.19		8		0						
11845	T		7.1		8		7.3		1			
11875	T		2.6				2.6		1			
11950	F		3.3				2.7		1			
12055	T		2.7				2.6		1			
12070	F	5.01	0.29	5				1				
12085	T	3.9				4.7		1				
12445	F	3.46	0.35	3				1				
12640	T			3		3.2	0			1		
12640	T		3.3			3.2	0		0	1		SS identified incorrect beam
12700	? T	2.2	2.9			<2	2.1	0	1			
12700	? F					<2	<2					
12745	? T	2.6	3.3			2.6	<2	1	0			
12745	? F					<2	<2					
13420	T		2.1				2.6		1			
13525	F	6.5	1.04	5				1				
13525	F		4.9			6.8	<2		0	1		SS identified incorrect beam
13635	T		3.7				6.6		1			
13635	F		3.7			3.8	4.1					Northstowe junction
13726	F	6.7	3.1			1.7	2.9	1	1			
13726	T	3.1				4.4		1				
13741	F	3.2				3.7		1				
13771	T	0.39	4.31		5	0	4.1		1			
13861	F		2.9				2.9		1			
13916	T	2.9				3.4		1				**Oakington junction**
14014	F - HFS					4.6	4.2			1	1	
14184	T		3				3.2		1			
14241	T				9	1.6	2.7				1	
14289	T				5	2.6	2.3			1	1	
14304	T		2.5				2.2		1			
14319	T	3.59	2.12	3				1	1			
14334	T				7		0					
14529	T				3		2.15				1	
14589	F	0.19	3.33	4		0	3.2		1			
14614	T	2.1	2.2			2.2	2.9	1	1			
14869	T	3.2				3.7		1				
14989	T	2.7				2.9		1				
15199	T	2.6				3.8		1				
15494	F	3.6				2.3		1				**Park Lane, Histon**
15586	T	8.1				7.8		1				
15586	F						9.9				1	
15796	T	2.4				3.4		1				
16051	T	7.2	2.9			1.5	4.5	0	1			
16051	F	7.9	7.8			8.4	6.4	1	1			**Histon ped xing (insitu)**
16061	T		4.4			4.2	2.7		1	1		
16061	F	11.3	3.5			12	3.1	1	1			
16136	F	6.6				2.7		1				
16211	T	3.1				0	3.9	0			1	SS identified incorrect beam
16316	T	3.4				1.1		0				
16376	T	2.2				2.7		1				
16391	F		8.6				8.8		1			
16406	F			3			2.3				1	
16421	T	2.3	2.2			2.9	2.8	1	1			
16451	T	2.1	2.6			2	2.2	1	1			
16496	T		5				5.7		1			
16511	F	3.1				3.7		1				
16556	F	3.4				4.2		1				
16751	F	2.1				2.7		1				
16766	T	4.3				4.3		1				
17006	T		2.4				3.4		1			
17081	T	4.8	2.1			5	2.8	1	1			
17096	T	3.5	2.3			3.2	2.9	1	1			
17181	T	8.79	1.04	13		10	1.8	1				
17196	T	3.02	0.9	5		3.1	1.1	1				
17226	F		11				11.3		1			
17226	T		3.6				4		1			
17241	T	2.1	3.4			1.5	3.8	0	1			
17321	T	0.21	5.27		5				1			
17321	F			5		4.5				1		
17341	T				4		2.8				1	
17376	T	2.6	3.4			2.7	4.2	1	1			
17391	T		2.4				2.8		1			

Defect 287

Page 2

	T - to Camb	Physical measurements										
	F - from Camb	Survey Solutions Investigation C (mm)		DEF287 (Apr 2014)		12/05/2016		SS DEFECT		ADDITIONAL		
Chainage	S - single	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	Comments
17431	F	2.9				6.4	1.4	1				Station Road, Histon
17531	F - HFS	7.3				9.1	4.5	1			1	
17531	T	3.4	9.2			1.4	6.8	0	1			
17571	T		5.5				4.3		1			
17586	T		2.1				2.9		1			
17631	F	6.52		6		7.2		1				
17631	F		10.02		6		10.9		1			
17661	T				3	2.9	2			1	1	
17691	F		2.3			2.4	2.1		1	1		
17691	T		3.8			3.4	2.3		1	1		
17721	F		2.7				3		1			
17736	T	2.7				2.6		1				
17751	T	2.6				2.8		1				
17781	F		2.4				3.6		1			
17781	T	3.8	7.3			5	20	1	1			
17796	T					15	2.6			1	1	
17811	T		3.3			1.1	5.6		1			
17826	T	0.37	2.56		3	1.2	3.3		1			
17841	T	2.86				3.6		1				
17886	T	4.01	5.8			2.8	6.2	1	1			
18111	F	2.8				3.1		1				
18186	F			3		2.6	1.9			1		
18261	F			13		1.7	0.9					
18291	T			2		0	0					
18321	F			2		1.7	1.3					
18366	F	0.32	3.36		4		3.2		1			
18441	F			2		0	1					
18456	T	3.86	2.41	4				1	1			
18486	F			4		3.1				1		
18501	F	2.5				2.8		1				
18516	T				3	0.6	1.8					
18516	F			4		1.9	1.9					
18561	T				2		0					
18576	T				2	1.6	1.8					
18621	T		3.4				3.4		1			
18681	T	0.38	2.52		4	1.5	3		1			
18681	F			4		2.1				1		
18696	T				2		2.2				1	
18711	T	3.5	1.27	4				1				
18741	T				3		2.5				1	
18741	F	2.96	0.33	4		3.5	1	1				
18756	T			4		2.4	2.3			1	1	
18771	T			3		2.1				1		
18801	T				2	1.6	2				1	
18801	F				3	1.1	1.7					
18816	T	0.7	2.68		3				1			
18816	F			3		2.5	0.8			1		
18876	T	2.88	1.3	3				1				
18906	F	5.8	3			9.1	5.6	1	1			
18906	T - HFS	6	8.9			7.4	8	1	1			Orchard Park Junction
19011	F - HFS	2.8	7.1			2.8	5.7	1	1			
19041	T				2		1.8					
19131	T	2.77	1.57	5		2.3	1.4	1				
19301												CRC junction
19415												
19425	T	4.4				0		0				Reset May 2016
19435	T	5.8				0		0				Reset May 2016
19465	F	6.6	3.6			7.1	5	1	1			
19465	T - HFS	7.2				5.9	3	1				CRC ped xing (insitu)
19475	F - HFS					2.5	1.8			1	1	
19475	T					3.5	3.3			1	1	
19625	F	3.1				3.4		1				
19640	F	1.66	6.65		10		7		1			
19685	F	2.6				2.5		1				
19685	T	3				2.5		1				
19835	T		2.5				2.8		1			
19910	F		2.8				2.5		1			
19985	F	0.31	3.33		5		3.3		1			
20030	F	0.95	4.15		5	1.3	4.4		1			
20270	F		2			0	3.6		1			
20270	T - HFS	5.5				8.6	4.1	1			1	Milton Rd ped xing (insitu)
20280	F - HFS	3.9	2.2			4.5	2.8	1	1			
20280	T	6.6	2			10	5.2	1	1			
20355												Milton Road
								97	114	24	23	

Trumpington

40538	F	2.2	2.6			2.2	3.1	1	1			
40568	F			4		2	2.1			1	1	
40658	F	4.88	0.02	7		5.7	0	1				
40718	F			6		1.3	1.8					
40808	T	2.1				2.5		1				
40853	F			6		1.9	1.3					
40988	T			2		1.5	0					
41118	T	0.84	2.17	4		3.1	1.4		1	1		SS identified incorrect beam
41373	T				4	2.1	1.5			1		

Defect 287 Page 3

	T - to Camb	Physical measurements										
	F - from Camb	Survey Solutions Investigation C (mm)		DEF287 (Apr 2014)		12/05/2016		SS DEFECT		ADDITIONAL		
Chainage	S - single	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	Comments
41463	F	2.4				1.8		0				
41703 to	41718											HILLS ROAD BRIDGE
41748	T	2.4				2.7		1				
41838	F				6	0	0					
41868	T	2.41	2.32	6		2.8	2.2	1	1			
41943	T			8		3.4	2			1	1	
42018	T			6		2.4	1.6			1		
42018	F				3	0	1.3					
42078	T			6		2.4	1.3			1		
42123	T			2		1.1	0					
42168	F	1.39	2.66		5	1.2	2.7		1			
42213	T				2	1.6	0					
42243	F				3	0	1.1					
42243	T	2.3				2.5		1				
42273	T			6		2.4	1.3			1		
42288	T	4	3			6.7	5.2	1	1			
42513	F - HFS	2.9				0	4.1	0			1	SS identified incorrect beam
42588	T - HFS	5.1	2.3			5.2	2.2	1	1			ADDENBROOKES LINK
42633	T			3		2.4	1.3			1		
42728	T	5.3	5.7			8.7	6.6	1	1			FOOTWAY - INSITU
42738	F	2.5				2.6		1				
42738	T - HFS	5.6				4		1				
42903	F - HFS		2.2				3		1			
42903	T	3.7	3.9			7.1	4.7	1	1			END DUAL GUIDEWAY
42982	S	4				3		1				START SINGLE GUIDEWAY
42997	S				5	0	2				1	
43072	S				7	0	1.3					
43087	S		2.6			2.6	1.3		0	1		SS identified incorrect beam
43132	S			7		0	1.4					
43152	S		2.2			2.4	0		0	1		SS identified incorrect beam
43202	S		2.6			2.9	1.6		0	1		SS identified incorrect beam
43212	S	3	2.4			2.4	3.1	1	1			
43222	S	2.3				2.3	3	1			1	
43232	S	2.7	2.1			2.2	3.1	1	1			
43242	S	4.1				1.5	4.7	0			1	SS identified incorrect beam
43302	S	2.2				1	3	0			1	SS identified incorrect beam
43312	S	4.8				6	1.7	1				
43442	S	2.89	2.07			3	2.3	1	1			
43492	S		2.7			2.5	3		1	1		
43502	S	2.25	1.52			2.4	1.9	1				
43532	S	2.9				3.9	1	1				END GUIDEWAY
								20	13	12	7	
Addenbrookes Link												
60052	F		4.2			5.4	6.8		1	1		START ADDENBROOKES LINK
60052	T	5.9				2	2.1	1			1	
60112	T				3	0	1.5					
60232	F		6.1			2.6	9.8		1	1		
60262	F	4.46	0.12	3				1				
60272	T		3.3			5	6.7		1	1		
60272	F	4.44	3.52		6	1.6	6.4	0	1			
60292	F	1.3	3.22		4				1			
60332	F	3.1				1	3.6	0			1	SS identified incorrect beam
60342	F	0.42	1.2		3	1.6	3.6				1	
60402	F		2				4.2		1			
60427	F	1.08	3.87		3				1			
60427	T		2.6				4.5		1			
60447	F	3.8				2.1	1.6	1				
60497	F	3.6	3.9			2.8	2.1	1	1			
60512	T	11.7	4.3			14	3.8	1	1			
60512	F	6.4	8.9			5.5	3.8	1	1			END ADDENBROOKES LINK
								6	11	3	3	
Orchard Park												
80135	F		2.2						1			
80125	F	2.3						1				
80445	F	15.1	4.2					1	1			
81257	F	2.2	2.8					1	1			
81272	F	4.5	3.2					1	1			
81272	T	3.7	4.6					1	1			
								5	5	0	0	

SUMMARY	Identified by SS		Additional identified by Supervisor		
	A (Outer)	B (Inner)	A (Outer)	B (Inner)	
North section	97	114	24	23	
Trumpington	20	13	12	7	
Addenbrookes Link	6	11	3	3	
Orchard Park	5	5	0	0	
TOTAL	128	143	39	33	343

Defect 287

Page 4

ATKINS

Atkins Limited

Your Ref:

Our Ref: 5047709/808/IH/L19763

BAM Nuttall Ltd
Cambridgeshire Guided Busway
4th Floor
80 New Bond Street
London
W1S 1SB

For the attention of Mr S Whalley, Project Manager

26 July 2016

Dear Sirs

Cambridgeshire Guided Busway

Defect Notification 288A - Beam Joint Relative Horizontal Displacement Defects

We write further to Defect 288A issued on 1 May 2014 to advise an increase in the number of non-compliant horizontal displacements since the issue of our original Defect Notice 288 on 18 October 2013.

Subsequent to the undertaking of Investigation C by Survey Solutions Ltd under the 'Guided Busway Testing and Investigative Contract' initiative between BAM and Cambridgeshire County Council, we were provided with a copy of those measurements and asked by the Employer to comment on apparent discrepancies between these measurements and the non-compliances list in our Defect Notice.

As a result of this request the Supervisor has undertaken a further survey, checking both the inner and the outer beams at each location identified in the Investigation C survey as exhibiting a non-conformance in addition to a further check at each location identified in our Defect 288A Notification

Our report in response to the Employer's request has been passed directly to Cambridgeshire County Council and its legal advisors.

The results of our check survey indicates a marked increase in the number of non-conformances since our July 2013 survey reported in the issue of the original Defect Notice.

Defect 288 reported 229 non-compliances (at 219 separate chainages) which exceeded the 2.0mm maximum horizontal step tolerance. The latest survey and audit has identified 504 such occurrences in excess of 2.0mm.

The results of the survey and audit are attached.

Yours faithfully
For and on behalf of Atkins Ltd

Ian Hodgkin
Supervisor

Enc Results of Atkins' re-survey
Cc Mr R Menzies – Cambridgeshire County Council – Service Director – Strategy and Development

DEFECT 288 HORIZONTAL GUIDEBEAM DISPLACEMENT

Chainage	T - to Camb F - from Camb S - single	Physical measurements: Survey Solutions Investigation C (mm)		Physical measurements: DEF288		Physical measurements: 12/05/2016		SS DEFECT		ADDITIONAL		Comments
		A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	
1708	T	3				3	0	1				
2068	F		2.5			2.6	2.9		1	1		
2098	T		2.5		3				1			
2128	F	2.5				**2.1**	0	1				
2293	T		3			3.1	2.7		1	1		
2323	F	3.5	2.2	4		3.9	2.9	1	1			
2398	T	3	3			3.3	2.9	1	1			
2533	F	2.5				**2.1**	**1.8**	1				
2548	F	3		4				1				
2623	T			4		3.3	2.2			1	1	
2638	T	3	3	3		3.2	3.2	1	1			
2713	F		2.5						1			
2758	F			3	3	0	0					
2788	F			3		2.9	0			1		
2833	F			3	3	1.9	3.6				1	
2848	F		4		4				1			
2908	F		4		4				1			
2923	F	2.5				3.8	0	1				
2923	T	2.2	3			2.6	3.9	1	1			
2983	F		3		3		2.4		1			
3013	F				3	**1.8**	2.2				1	
3028	F	2.5		3	3	2.6	2.6	1			1	
3088	T		2.5			0	1.9		0			
3238	T	4	4		4	3.2	4.8	1	1			
3253	F	3		3				1				
3433	T	2.5	2.5			3.2	2.6	1	1			
3523	T		2.5			3	3.7		1	1		
3673	F	4.2	3.5	3		4.2	3.2	1	1			
3778	F	2.5	2.5	4		3.3	2.8	1	1			
3853	F				3	2.4	2.4			1	1	
3928	F				3	2.3	2.4			1	1	
3988	T		3			0	3		1			
4018	F		2.5			0	2.4		1			
4083	F		3			0	3.8		1			
4098	F	3	3		4	3.1	3	1	1			
4138	T	2.2	3	3		2.5	3.6	1	1			
4168	T	2.2	3		3	2.4	3.5	1	1			
4288	T				4	0	2.9				1	
4528	F		4		4				1			
4558	T		2.5			0	2.2		1			
4588	T		2.5			2.2	3.6		1	1		
4708	F	3				3.2	0	1				
4708	T	2.5				2.4	0	1				
4723	T	3				2.7	0	1				
4798	F			4		3	0			1		
4843	T	4		4				1				
4888	F			3		2.4	3.1			1	1	
4903	T	3.5			3	4.2	2.7	1			1	
5023	T	3		3				1				
5093	T				3	0	1.7					
5103	F			3		**2.2**	0			1		
5413	T			3		2.5	**2.1**			1	1	
5443	T		2.5		3				1			
5718	T	4		4				1				
5753	T		3		4				1			
5768	F	3		3				1				
5778	T			3		2.9	**1.6**			1		
5788	T	3		3				1				
5803	F	3		3				1				
5848	T	2.2	3	3		2.7	3.8	1	1			
5878	T				3	0	4				1	
5998	F	3	3	3		3.7	2.9	1	1			
6103	T	2.5	2.5	3		3.8	4.5	1	1			
6163	F		3		3				1			
6298	T	3	2.5		3	4.3	3.8	1	1			
6358	F		2.2			2.2	2.8		1	1		
6388	F	4	4		3	4.9	3.8	1	1			
6418	T		2.5			0	4		1			
6478	T		3			0	2.7		1			
6523	F	**2.2**		4		3.2	0	1				
6743	F		2.2			0	2.9		1			
6763	F	3		3				1				
6868	F		4		3				1			
7123	T			3		3.2	1.3			1		
7183	F	5	2	4		5.5	3.7	1	1			
7198	F	3				3	2	1			1	
7333	F			4		3.2	1.3			1		

Defect 288 Page 1

	T- to Camb	Physical measurements										
	F - from Camb	Survey Solutions Investigation C (mm)		DEF288		12/05/2016		SS DEFECT		ADDITIONAL		
Chainage	S- single	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	Comments
7393	T				4	0	3.4				1	
7408	T	5	4	4		5.9	5.2	1	1			
7423	F				3	0	2.4				1	
7498	F	2.5				2.9	0	1				
7528	T		3.5			2.6	3.3		1	1		
7543	T				3	2.4	2.6			1	1	
7543	F	2.5	6	3		2.8	5.9	1	1			
7558	T		4			2.6	4.5		1	1		
7618	T				3	0	1.8					
7693	F			4		3.5	3.1			1	1	
7708	T			3		3.1	0			1		
7723	T			3		3.4	0			1		
7828	F	4				2	4.4	1			1	
7843	T		3			0	3.2		1			
7873	F	2.2		4		3.2	1.2	1				
7903	T	8	8	4		8.2	8.1	1	1			
7903	F	2.5	5		6	3.4	5.9	1	1			
7948	F		4	3		4.2	1.5		0	1		SS identified incorrect beam
7978	F		3.5			0	3.7		1			
8008	f		2.2			0	2.8		1			
8008	T		3		4				1			
8023	F	6	4	4		6.3	4.1	1	1			
8048	T		2.5			0	3.1		1			
8158	F		2.2			0	2.7		1			
8218	T			3		2.4	1.4			1		
8248	F		4.5		6				1			
8353	F			5		2.3	2.5			1	1	
8428	F	3				3.4	0	1				
8488	T			3		2.2	0			1		
8503	F	2.5				2.8	<2	1				
8503	T				3	0	0.8					
8578	T				3	2.3	2.5			1	1	
8608	T				3	0	2.1				1	
8608	F	3	2.5	3		3.6	2.5	1	1			
8638	T			3		1.7	2.2				1	
8638	F	3		4		3.3	0	1				
8698	T			4		2.3	0			1		
8713	F	5	4	4		6.8	5.4	1	1			
8728	T	4		4		2.7	0	1				
8728	F	2.5	2.5		3	2.9	3.2	1	1			
8773	F		3			0	3.2		1			
8818	T	4.5		5				1				
8818	F	3	5		3	3.4	5.9	1	1			
8833	F	5	2	4		5.5	2.1	1	1			
8848	F			4		2.3	2			1	1	
8893	F	5	6	5		6	7.5	1	1			
8968	F	5	2			6.3	3.7	1	1			
8998	F		2.2			0	2.8		1			
9013	T			3		2.4	0			1		
9028	F	5.2	5.2	5		7.4	5.7	1	1			
9103	F	2.2	4		4	2.7	4.2	1	1			
9148	F	4	4			3.7	3.8	1	1			
9163	F		2			1.8	2.5		1			
9178	F		2.5			2	2.7		1	1		
9238	F	2				2.8	1.8	1				
9298	F	3.2	3	4		4.4	2.7	1	1			
9313	F	2	2			2.1	2.1	1	1			
9313	T		3.2			<2	3.1		1			
9328	T	2.2		3				1				
9343	F	2.2				<2	3.3	0			1	SS identified incorrect beam
9358	T		4			0	2.3		1			
9388	F	3.8	2.5		3	3.5	3.2	1	1			
9403	F		3			<2	3.3		1			
9433	F		2			0	2.3		1			
9523	F	3.2		3				1				
9538	T	3.2		4				1				
9583	F	2.5		3				1				
9628	T		3		3				1			
9688	T	3.2	3.2	5		4.3	4.4	1	1			
9703	F	3.2	3.2		4	4.7	3.5	1	1			
9718	F		2			0	2.4		1			
9763	F		2.5			1.1	2.3		1			
9793	F		2.5			1.6	2.6		1			
9838	F		2.5			0	2.8		1			
9868	F	2				2	0	1				
9868	T	2	2		5	2.8	2	1	1			
9883	T	2	2.4		6	2.2	2.7	1	1			
9898	T	2.4	3.9			2.8	4.1	1	1			
9908	F	2.5				1	1.9	0				

Defect 288

Page 2

	T-to Camb	Physical measurements										
	F - from Camb	Survey Solutions Investigation C (mm)		DEF288		12/05/2016		SS DEFECT		ADDITIONAL		
Chainage	S - single	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	Comments
10005	F	4	4		5	5.2	4.8	1	1			
10165	T		2.5			<2	3.1		1			
10255	F		2.5			**2.1**	3.4		1	1		
10255	T	5	5	3		5.6	5.8	1	1			
10480	T	4	4.5			4	4.6	1	1			
10540	T	3				3.1	0	1				
10585	F	3		3				1				
10585	T	3	2.5			2.9	2.6	1	1			
10600	T	3				2.7	0	1				
10630	T		2.5			0	3.2		1			
10675	T		3			<2	**2.8**		1			
10720	T		2.5			1.9	3.3		1			
10750	T	3	4			2.9	4.3	1	1			
10810	F				4	1.5	3.1				1	
10825	F			3		3.7	**1.8**			1		
10855	T	3	3.5		4	3.9	4.2	1	1			
10945	F	3				3.7	**1.8**	1				
10975	T	3	3			3.7	2.3	1	1			
11035	F		3.8			0	0.9		0			SS identified incorrect track
11035	T					0	4.1				1	
11065	T			3		**2.8**	2.4			1	1	
11095	T	3.5	4.5	3		3.3	4.5	1	1			
11110	T		4		4	4.5	5.6		1	1		
11140	T	6	6		6	6.7	7.5	1	1			
11215	T	3	3			**2.8**	4	1	1			
11245	T	3	4		3	4.7	6.2	1	1			
11290	T	5	5	5		4.9	4.7	1	1			
11320	F		3			2.5	3.4		1	1		
11335	T	2.5				2.3	**2.2**	1			1	
11365	F	2.5	2.5			2.3	2.3	1	1			
11365	T	3				3.1	<2	1				
11380	F		3	5		2.9	3.5		1	1		
11425	T	6	6	5		5.4	5.8	1	1			
11500	T	3.5	4.5	4		3.3	4.4	1	1			
11515	T		2.5			0	**2.8**		1			
11530	T	4	3	4		5	3.6	1	1			
11530	F		3.5		3	**1.8**	3.8		1			
11590	F				3	2.7	2.3			1	1	
11590	T		2.5			**2.8**	3.4		1	1		
11620	T	3	3		3	3	2.9	1	1			
11710	F	3	4			4	4.2	1	1			
11755	F		4			0	4.2		1			
11755	T		2.5			0	3.2		1			
U785	F				3	0	**2.8**				1	
11800	T	2.5				3.9	2.7	1			1	
11800	F	4	6			3.4	4	1	1			
11815	T	4	5			5.4	4.6	1	1			
11890	T	5	6	6	6			1	1			
11905	T		3			0	3.2		1			
11980	T	2.5	3			2.9	3.3	1	1			
11995	T		3			0	3		1			
12025	F			3		2.2	0			1		
12220	T	3		3				1				
12370	F	2.5				3.6	**2.1**	1			1	
12490	T	5	5		4	6.2	6.8	1	1			
12520	T	4.5		4				1				
12565	T	3.5				3.3		1				
12595	T			3		0	2.3				1	
12670	T			3		**2.1**	0			1		
12685	T	3				3.5	2.7	1			1	
12700	T	2.5		4		2.9	1.3	1				
12730	F		3.5		3				1			
12745	T			4		2.3	0			1		
12790	T	2.2	4.5			2.9	4	1	1			
12910	T		3			0	**2.8**		1			
13060	T		3	3		2.9	3.1		1	1		
13120	T	2.5		4				1				
13165	T		3			0	2.9		1			
13255	F		3			<2	3.4		1			
13315	T	3	3		5	3.2	3.7	1	1			
13360	F			4		3.4	0			1		
13390	T	3				2.6	0	1				
13435	T	4				4.4	0	1				
13560	T	3	4	3		4.8	4.7	1	1			
13590	T				3	3	**2.1**			1	1	
13741	F	3		3				1				
13741	T	3				4	0	1				
13756	T		2.5			**2.1**	3		1	1		
13786	T	3	3	3		3.7	3.1	1	1			

Defect 288

Page 3

	T-to Camb	Physical measurements										
	F - from Camb	Survey Solutions Investigation C (mm)		DEF288		12/05/2016		SS DEFECT		ADDITIONAL		
Chainage	S - single	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	Comments
13801	T	3.8	3	4		4.2	3.7	1	1			
13801	F		3			0	3.1		1			
13831	T		4			2.8	4.2		1	1		
13861	T	3.5				3.1	0	1				
13891	T				3	3.3	3.3			1	1	
13906	T			3	3	**1.8**	3.4				1	
14024	T	5	3			5.1	4.8	1	1			
14024	F		4			2.8	4.4		1	1		
14034	T		3		3				1			
14079	F		4		4				1			
14154	T	3.8	3.8		4	4.3	4.2	1	1			
14214	F	4	5		5	4	7	1	1			
14244	F	3	4		4	3.7	5.9	1	1			
14274	F			4		2.9	**1.8**			1		
14289	T	3	3			2.9	3.1	1	1			
14364	T		2.2			**1.8**	**2.8**		1			
14424	F		3			0	3		1			
14409	T				3	2.4	2.9			1	1	
14424	F		3		3				1			
14514	F		3		3				1			
14544	T	2.5				**2.8**	**1.8**	1				
14574	F	3				4.1	**1.8**	1				
14599	T	4				4.2	**1.6**	1				
14644	T	2.5				3.5	0	1				
14794	T	**2.2**				2.9	0	1				
14839	F			4		2.6	0			1		
15064	F		2.5	3		2.9	2.8		1	1		
15409	T	2.5				2.7	**1.6**	1				
15469	T	2.5	2.2			3.1	2.4	1	1			
15616	F				3	2.4	**1.8**			1		
15661	F		3		4				1			
15691	F	2.5				1.9	0	0				
15721	F				3	**1.2**	2.2				1	
15871	T			4		3.4	0			1		
15946	T	**2.2**		3				1				
15976	T		5		6				1			
16121	T		2.3			0	2.9		1			
16361	T	3	2.5		3	3.4	2.9	1	1			
16391	F	3		3				1				
16406	F	2.5	3.5	3		2.7	3.9	1	1			
16421	T	3	3.5	4		3.8	3.5	1	1			
16466	T	2.2				3	0	1				
16556	T	4		5				1				
16571	F	2.5		4				1				
16781	T	3.5			4	4.1	3	1			1	
16826	F		4		5				1			
16916	T				5	2.9	2.4			1	1	
17151	T	4	3.5	5		4.7	4.2	1	1			
17181	T	4				5.2	4.3	1			1	
17241	T	2			3	3.5	0	1				
17271	T				3	3.3	0			1		
17286	T	5			4	6	4.2	1			1	
17406	T	2.5		3				1				
17541	F	**6**	5			3	1.5	1	0			
17556	T		3.5			3.4	4.4		1	1		
17571	F		3			**1**	4.1		1			
17586	T	6	4			3.2	1.4	1	0			
17601	T	4		3				1				
17631	F			6	6	7.4	7.3			1	1	
17646	F	7.5	4	7		7.6	4.5	1	1			
17676	F			4		3	**1.8**			1		
17691	T	6	9	6		4.3	3.6	1	1			
17691	F			3		0	0					
17706	T			3	3	**6.8**	3.3			1	1	
17706	F	5				**1**	0.9	0				
17721	F				5	**1**	3.6				1	
17736	T			4		0	0					
17751	F		3			1.4	2.9		1			
17766	F		2.5			3.1	3		1	1		
17781	T	6	**10**		7	3.7	7.5	1	1			
17781	F	7	7.5	4		8.3	9	1	1			
17796	T		3.5			**1.2**	**1.1**		0			
17796	F	2.5	3.5			4.9	5.8	1	1			
17811	T	4	3.5		5	3.3	2.7	1	1			
17826	T	2.5				**1.6**	0	0				
17841	F			4		**1.2**	3.2				1	
17856	T	7	5	4		7.2	6.6	1	1			
17886	T	3				**2.8**	2.5	1			1	
17886	F	3	3			3.3	3.4	1	1			

Defect 288

Page 4

Chainage	T-to Camb F - from Camb S - single	Physical measurements Survey Solutions Investigation C(mm)		DEF288		12/05/2016		SS DEFECT		ADDITIONAL		Comments
		A (Outer)	B (inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	A (Outer)	B (Inner)	
17946	F			3		1.9	0					
18171	F	3.5		4				1				
18186	T				3	1.5	3				1	
18216	T		2.5			**1.6**	3		1			
18321	T				3	2.9	3.8			1	1	
18336	F			3		2.6	0			1		
18351	T	2.5				4	2.5	1			1	
18471	T		2.5		4	**1.1**	3		1			
18501	T		2.5		5	0	3.3		1			
18666	T				3	0	2.4				1	
18726	T				3	**2.1**	2.7			1	1	
18891	T			3		2.7	0			1		
19056	T		3.5		6	0	3.7		1			
19146	T			3		**2.2**	1.7			1		
19251	F				4	2	3.3			1	1	
19535	F			4		2.9	**1.2**			1		
19625	F	3				3.9	0	1				
19685	T	5	4	5	5			1	1			
19820	T	4		4				1				
19835	T	3	3	4		4.8	4.4	1	1			
19925	F				4	1	2.5				1	
19970	T		2.5			0	3		1			
20210	T	2.2	3			2.4	2.4	1	1			
20255	T			3		2.4	1.7			1		
								166	177	70	54	
Trumpington												
40808	F	2.5				3.2	<2	1				
40838	T		3		5	3.3	3.3		1	1		
41003	F	2.5				3.3	1.3	1				
41343	F			4		2.2	1			1		
41373	F		2.5			0	2.8		1			
41418	F			3		**1.8**	1.5					
41448	F	4		5				1				
41463	F			3		2.4	**1.6**			1		
41793	T		2.5		3				1			
41808	T		3.5			2.6	3.5		1	1		
41838	F		3		**6**	2.2	3.3		1	1		
41868	T			**6**		1.7	0					
41928	T	3				3.2	1.9	1				
42198	F	3		4				1				
42243	F				3	1	3				1	
42258	F		3			2.4	2.8		1	1		
42258	T	4				4.4	0	1				
42603	F				3	2	2.9			1	1	
42618	F				3		3				1	
42708	T			3		1.7	0					
42798	T		3			**2.1**	2.7		1	1		
42813	T		3			1.7	3.1		1			
43172	S	3.5	3.5			3.6	4.1	1	1			
43212	S	3				3.7	1.5	1				
43482	S		4			0.9	4.3		1			
								8	**10**	8	3	
Addenbrokes Link												
60302	F	3										
60332	F		3			1.5	4.9		1			
60417	T	5	3	4	4			1	1			
60427	T	2.5				**2.1**	0	1				
								2	2	0	0	
Orchard Park												
80115	F	3.5						1				
80105	F	3.5						1				
80075	F		2.5						1			
80065	F	3						1				
								3	1	0	0	

SUMMARY	identified by SS		Additional identified by Supervisor		
	A (Outer)	B (Inner)	A (Outer)	B (Inner)	
North section	166	177	70	54	
Trumpington	8	**10**	8	3	
Addenbrookes Link	2	**2**	0	0	
Orchard Park	3	**1**	0	0	
TOTAL	179	190	78	57	504

Defect 288

Page 5

APPENDIX E – INVESTIGATION F SUMMARY

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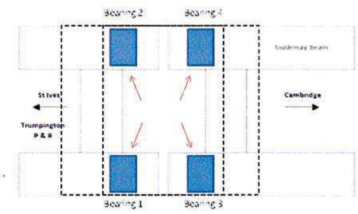
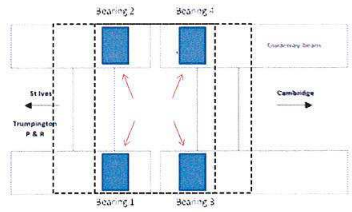
INVESTIGATION F SUMMARY



File name of photograph takes the form ch[chainage]_[Direction]_[Bearing Number].jpg

Chainage	Date	TO/ FROM	Steps 6-5 mm Outer To Camb	Steps 8-7 mm Inner To Camb	Steps 6-5 mm Inner From Camb	Steps 8-7 mm Outer From Camb	Inv C mm Outer	Inv C mm Inner	Comments on F1 Photographs 2-4 is Outer Beam; 1-3 is Inner Beam to Cambridge 2-4 is Inner Beam; 1-3 is Outer Beam from Cambridge
4303	42352	T	15.12	1.54			16.3	2.1	1: shims and/or bearing coming out, probably in excess of 100mm relative movement. Bearing looks to have moved towards the beam end / joint. 2: Bearing & bottom shim coming out, both projecting forward of the bearing shelf edge. Other shims displaced relative to bearing (see also photo for bearing 4) 3: Some relative movement between bearing and shims but obscured by bearing which has come out. 4: Step, damage / spalling to bottom edge at end of dropped beam! Bearing and shims not visible, bearing out?
4318	42352	T	1.83	2.78					1: Shims slightly displaced relative to bearing 2: Shims slightly displaced relative to, and overhanging, bearing 3: Shims slightly displaced relative to, and overhanging, bearing 4: Shims slightly displaced relative to, and overhanging, bearing. Twist in spacer beam evident.
5708	42352	F			1.28	3.07	3.1		1: Shims slightly displaced relative to bearing 2: Shims slightly displaced relative to bearing 3: Top shim displaced relative to other shims and bearing 4: Shims slightly displaced relative to bearing
5718	42352	F			4.57	2.85	3.4	6.3	1: Shims parting, beam lifting? Shadow gaps at interfaces evident. 2: Shims rotated and displaced relative to bearing. Bearing pad displaced laterally towards centre of guideway ladder. 3: Shims slightly displaced relative to bearing. 4: Shims slightly displaced relative to bearing.
5983	42352	F			3.26	2.11			1: Bearing out? Shims displaced over bearing 2: Top shim slightly displaced relative to other shims and bearing 3: Bearing and shims overhanging edge of bearing shelf 4: Bearing and shims displaced? Overhanging edge of bearing shelf.
5998	42352	F			3.08	0.06		3.3	1: Shims parting and displaced relative to bearing 2: Shims slightly displaced relative to bearing 3: Shims slightly displaced relative to bearing 4: Shims slightly displaced relative to bearing
6713	42352	F			0.62	3.24	4.9	1	1: Shims parting, beam lifting? 2: Shims slightly displaced relative to bearing. 3: Shims slightly displaced relative to bearing. 4: Shims slightly displaced relative to bearing.
6723	42352	F			2.15	0.14			1: Top shim displaced relative to lower shims and bearing pad. 2: Shims slightly displaced relative to bearing 3: Beam lifting off? Shadow gap at interface of guideway and top shim. 4: Bearing pad displaced beyond edge of bearing shelf. Shims displaced relative to bearing.
7588	42352	F			10.7	3.04		13.7	1: Shims slightly displaced relative to bearing. 2: Bearing / shims slightly displaced relative to each other. 3: Bearing / shims look to be aligned, no obvious or discernible displacement. 4: Step, end of guideway beam dropped relative to bearing 2. Bearing pad and/or shims not evident in photo!
7603	42352	F			1.55	2.57			1:Bearing / shims slightly displaced relative to each other. 2: Bearing / shims slightly displaced relative to each other. Localised distortion to shims evident? 3: Bearing / shims slightly displaced relative to each other. Some gaps / distortion in shims? localised shadow gaps at interfaces may, however, also be as a result of lateral movements. 4: Insufficient access - No photo
8048	42352	T	0.89	6.73			2.4	9.9	1: Bearing / shims displacing relative to each other. Both longitudinal and transverse displacements evident. 2: Bearing / shims displacing relative to each other. 3: Bearing squeezed out. Shims displaced relative to each other. 4: Bearing / shims displacing relative to each other.
8058		T	3.36	4.13					1: Bearing / shims displacing relative to each other. 2: Bearing / shims displacing relative to each other. 3: Bearing / shims displacing relative to each other. Both longitudinal and transverse displacements evident. 4: Bearing / shims displacing relative to each other.
9343	42353	F			2.37	0.05		5.3	1: Bearing / shims, minor displacements relative to each other. 2:Bearing almost out. Longitudinal movements, pad hanging over edge of bearing shelf, evident. Lateral movements evident from bearing / shims displacing relative to each other. 3: Bearing / shims, minor displacements relative to each other. 4: Bearing / shims look to be aligned, no obvious or discernible displacement.
10016	42352	F			5.45	1.12		7.3	1: Bearing / shims, minor displacements relative to each other. 2: No bearing visible, shims coming out. Gaps between shim to shim and shim to concrete interfaces. 3: Bearing / shims, minor displacements relative to each other.

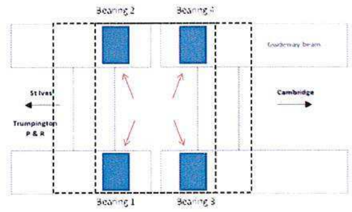
INVESTIGATION F SUMMARY



File name of photograph takes the form ch[chainage]_[Direction]_[Bearing Number].jpg

Chainage	Date	TO/ FROM	Steps 6-5 mm Outer To Camb	Steps 8-7 mm Inner To Camb	Steps 6-5 mm Inner From Camb	Steps 8-7 mm Outer From Camb	Inv C mm Outer	Inv C mm Inner	Comments on F1 Photographs 2-4 is Outer Beam; 1-3 is Inner Beam to Cambridge 2-4 is Inner Beam; 1-3 is Outer Beam from Cambridge
10495	42352	T	1.92	9.91				9.7	1: Bearing / shims, minor displacements relative to each other. 2: Bearing / shims, minor displacements relative to each other. 3:Bearing "nearly" out, displaced longitudinally off bearing shelf and transversely towards the outside of the ladder assembly. 4: Bearing / shims displacing relative to each other.
10510	42352	T	0.47	1.53					1: Bearing / shims displacing relative to each other. Both longitudinal and transverse displacements evident. 2: Bearing / shims displacing relative to each other. 3: Bearing / shims displacing relative to each other. 4: Bearing / shims displacing relative to each other.
11051	42353	F			2.03	1.15			1: Bearing / shims displacing relative to each other. 2: Bearing / shims displacing relative to each other. 3: Bearing / shims displacing relative to each other. 4: Bearing / shims displacing relative to each other.
11066	42353	F			6.83	0.58	2.1	7.6	1: Shims coming out relative to bearing. Bearing moved back from edge of bearing shelf? 2: Bearing almost out. Longitudinal movements, pad hanging over edge of bearing shelf, evident. Lateral movements evident from bearing / shims displacing relative to each other. 3: Bearing / shims look to be aligned, no obvious or discernible displacement. 4: Bearing / shims displacing relative to each other.
11276	42353	F			1.39	1.06			1: Bearing / shims displacing relative to each other. Both longitudinal and transverse displacements evident. 2: Bearing / shims displacing relative to each other. 3: Bearing at edge of bearing shelf? Bearing / shims displacing relative to each other. 4:Bearing out of position both longitudinally (edge should be 50mm back from centre of joint, estimate to be around 10mm in photograph) and laterally (edge should be around 250mm from inside edge of beam, seems to be at back of lateral restraint bracket, that is at beam edge, in photograph). Second photograph shows edge of bearing more or less at inside edge of beam. Spacer beam looks to be twisted?
11291	42353	F			3.69	2.1		2.7	1: Bearing / shims displacing relative to each other. 2: Bearing / shims displacing relative to each other. 3: Bearing / shims displacing relative to each other. 4: Bearing / shims displacing relative to each other.
11816	42353	T	9.66	3.35			11.3	3.5	1: Bearing / shims displacing relative to each other. 2: Bearing / shims displacing relative to each other. 3: Bearing / shims displacing relative to each other. 4: Bearing and/or shims coming out. Bearing moved out laterally and projecting beyond internal face of guideway beam. Guideway beam dropped in level relative to spacer beam.
11831	42353	T	0.61	1.54				2.4	1: Bearing/shims displaced laterally and coming out. Bearing rotating about edge of lateral restraint bracket and coming out beneath spacer beam. 2: Bearing / shims look to be aligned, no obvious or discernible displacement. 3: Bearing / shims displacing relative to each other. Both longitudinal (approx. 60mm) and transverse displacements evident. 4: Bearing / shims displacing relative to each other.
13526	42353	F			0.31	4.85	6.5		1: Bearing / shims displacing relative to each other. 2: Bearing / shims displacing relative to each other. 3: Bearing and shims almost out. Pad bearing hanging over edge of bearing shelf? 4: Bearing / shims look to be more or less aligned, no obvious displacements.
14319	42353	T	3.22	1.28			3.5	2.1	1: Bearing / shims displacing relative to each other. Both longitudinal and transverse displacements evident. 2: Bearing / shims look to be aligned, no obvious or discernible displacement. 3: Bearing / shims displacing relative to each other. 4: Bearing / shims displacing relative to each other.
15586	42353	T	7.7	1.31			8.1		1: No photo (Slab Interface) 2: No photo (Slab Interface) 3: Bearing / shims coming out relative to each other 4: Bearing / shims coming out relative to each other
15601	42353	T	2.04	0.3					1: Bearing / shims slightly displaced relative to each other. 2: Bearing / shims slightly displaced relative to each other. 3: Bearing / shims slightly displaced relative to each other. 4: Bearing / shims slightly displaced relative to each other.
16051	42354	F			7.2	11.26	7.9	7.8	1: Bearing / shims displacing relative to each other. 2: Bearing / shims displacing relative to each other. 3: No photo (Slab Interface) 4: No photo (Slab Interface)
16051	42354	T	7.47	6.24			7.2	2.9	1: Bearing / shims displacing relative to each other. Both longitudinal and transverse displacements evident. 2: Bearing / shims displacing relative to each other. 3: No photo (Slab Interface) 4: No photo (Slab Interface)
16061	42354	F			8.4	8.36	11.3	3.5	1: No photo (Slab Interface) 2: No photo (Slab Interface) 3: Bearing / shims look to be aligned, no obvious or discernible displacement. 4: Bearing / shims displaced relative to each other. Shims / bearing coming out?

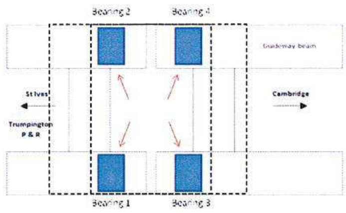
INVESTIGATION F SUMMARY



File name of photograph takes the form ch[chainage]_[Direction]_[Bearing Number].jpg

Chainage	Date	TO/ FROM	Steps 6-5 mm Outer To Camb	Steps 8-7 mm Inner To Camb	Steps 6-5 mm Inner From Camb	Steps 8-7 mm Outer From Camb	Inv C mm Outer	Inv C mm Inner	Comments on F1 Photographs 2-4 is Outer Beam; 1-3 is Inner Beam to Cambridge 2-4 is Inner Beam; 1-3 is Outer Beam from Cambridge
16061	42354	T	4.65	2.41				4.4	1: No photo (Slab Interface) 2: No photo (Slab Interface) 3: Bearing / shims slightly displaced relative to each other. 4: Bearing / shims slightly displaced relative to each other.
16076	42354	F			0.68	0.45			1: Bearing / shims slightly displaced relative to each other. 2: Bearing / shims look to be aligned, no obvious or discernible displacement. 3: Bearing / shims slightly displaced relative to each other. 4: Bearing / shims look to be aligned, no obvious or discernible displacement.
16391	42353	F			8.65	1.92		8.6	1: Bearing / shims displaced relative to each other. 2: Bearing pad and shims completely displaced relative to each other. Shims and bearing beside each other. 3: Bearing / shims displacing relative to each other. 4: Bearing / shims slightly displaced relative to each other.
17181	42353	T	6.92	0.05			8.8		1: Bearing / shims slightly displaced relative to each other. 2: Bearing / shims slightly displaced relative to each other. 3: Bearing / shims displacing relative to each other. 4: Bearing and/or shims out?
17196	42353	T	0.84	0.62			3		1: Bearing / shims slightly displaced relative to each other. 2: Bearing / shims slightly displaced relative to each other. 3: Bearing / shims look to be aligned, no obvious or discernible displacement. 4: Shims parting, beam lifting?
17226	42353	F			8.76	0.99		11	1: Bearing / shims look to be aligned, no obvious or discernible displacement. 2: Bearing / shims look to be aligned but all out of position and just over edge of bearing shelf. 3: Bearing / shims look to be aligned, no obvious or discernible displacement. 4: Bearing almost out, hanging over edge of bearing shelf.
17241	42353	F			2.29	0.3			1: Bearing / shims look to be aligned, no obvious or discernible displacement. 2: Bearing / shims look to be aligned, no obvious or discernible displacement. 3: Bearing / shims slightly displaced relative to each other. 4: Bearing / shims slightly displaced relative to each other.
17531	42354	F			5.66	8.06	7.3		1: No photo (Slab Interface) 2: No photo (Slab Interface) 3: Displaced shims which are twisted relative to bearing 4: Possibly no shims or 1 No. 2mm aligned shim
17531	42354	T	5.72	18.5			3.4	9.2	1: No photo (Slab Interface) 2: No photo (Slab Interface) 3: Bearing and shims out, displaced out longitudinally and off of bearing shelf. Photo aligns with readings. 4: Bearing displaced, overhanging edge of bearing shelf. Photo aligns with readings.
17541	42354	F			1.08	0.9			1: Bearing / shims displaced relative to each other. 2: Bearing / shims slightly displaced relative to each other. 3: Bearing only visible -shims out? 4: Bearing only visible, no shims evident.
17541	42354	T	2.3	2.06					1: Shims displaced and/or gap at top of bearing, beam "lifting"? 2: No bearing, shims displaced, gap? 3: No shims visible 4: No shims visible
17616	42353	F			0.02	1.23			1: Bearing / shims displacing relative to each other. 2: Bearing / shims displacing relative to each other. Top shim projecting out towards edge of bearing shelf. 3: Bearing / shims displacing relative to each other. Top shims projecting out towards bearing shelf? 4: Bearing / shims displacing relative to each other.
17631	42353	F			10.04	6.36		10	1: No bearing pad visible, bearing out? Shims displaced relative to each other. 2: Bearing out and shims displaced relative to each other. Gap between shims and beam? 3: Bearing / shims displaced relative to each other. 4: Bearing / shims slightly displaced relative to each other.
17781	42354	T	2.62	15.02			3.8	15.3	1:Bearing / shims displaced relative to each other. 2: Bearing / shims slightly displaced relative to each other, excessive shims. 3: Bearing out, shims displaced relative to each other, over edge of bearing shelf, excessive shims. 4: Bearing / shims slightly displaced relative to each other, excessive shims
17796	42354	T	0.98	0.44					1: Bearing / shims displacing relative to each other. Excessive shims. 2: Bearing / shims displaced relative to each other. Bearing and/or shims coming out. Excessive shims. 3: Bearing / shims slightly displaced relative to each other. Assembly looks to be out of position, too close to edge of bearing shelf? Excessive shims. 4: Bearing / shims slightly displaced relative to each other. Assembly looks to be out of position, too close to edge of bearing shelf? Excessive shims.
18906	42354	F			10.55	10.62	5.8	3	1: Bearing / shims look to be aligned, no obvious or discernable displacement. 2: Bearing / shims slightly displaced relative to each other. 3: No photo (Slab Interface) 4: No photo (Slab Interface)

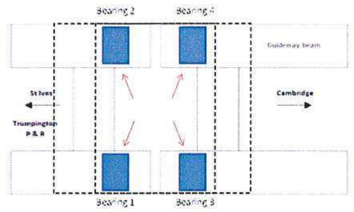
INVESTIGATION F SUMMARY



File name of photograph takes the form ch[chainage]_[Direction]_[Bearing Number].jpg

Chainage	Date	TO/ FROM	Steps 6-5 mm Outer To Camb	Steps 8-7 mm Inner To Camb	Steps 6-5 mm Inner From Camb	Steps 8-7 mm Outer From Camb	Inv C mm Outer	Inv C mm Inner	Comments on F1 Photographs 2-4 is Outer Beam; 1-3 is Inner Beam to Cambridge 2-4 is Inner Beam; 1-3 is Outer Beam from Cambridge
18906	42354	T	8.59	14.71			6	8.9	1: Bearing / shims slightly displaced relative to each other. 2: Bearing / shims slightly displaced relative to each other. 3: No photo (Slab Interface) 4: No photo (Slab Interface)
20280	42354	T	10.74	5.07			6.6	2	1: No photo (Slab Interface) 2: No photo (Slab Interface) 3: Bearing / shims slightly displaced relative to each other. 4: Bearing / shims look to be aligned, no obvious or discernable displacement.
SOUTHERN SECTION									
40658	42354	F			0.38	6.33	4.9		1: Bearing and shims out? 2: Bearing / shims look to be aligned, no obvious or discernable displacement. 3: Bearing / shims displaced relative to each other. 4: Bearing / shims displaced relative to each other.
42588	42354	T	5.66	0.24			5.1	2.3	1: Bearing / shims slightly displaced, possibly rotated/twisted relative to each other. 2: Bearing / shims slightly displaced relative to each other. 3: No photo (Slab Interface). 4: No photo (Slab Interface).
43232	42354		1.63	2.73			2.7	2.1	1: Bearing / shims possibly twisted. Partly obsured and poor photograph. Material "poured" around bearing to hold/fix in place? 2: Material "poured" around bearing to hold/fix in place? 3: Bearing partly obsured and poor photograph. Material "poured" around bearing to hold/fix in place? 4: Material "poured" around bearing to hold/fix in place?
43242	42354		0.8	3.9			4.1		1: Bearing / shims displaced relative to each other. Longitudinal movement, edge of bearing and shims at or approaching extent of bearing shelf? 2: No shims? 3: Bearing partly obsured and poor photograph. Material "poured" around bearing to hold/fix in place? 4: Bearing partly obsured and poor photograph. Material "poured" around bearing to hold/fix in place? No shims?
43252	42354		0.72	1					1: No shims ? 2: Bearing / shims look to be aligned, no obvious or discernable displacement. Material "poured" around bearing to hold/fix in place? 3: Bearing / shims displaced relative to each other. Both longitudinal and transverse displacements evident. 4: Bearing / shims slightly displaced relative to each other?
43312	42354		4.42	0.9			4.8		1: Bearing / shims slightly displaced relative to each other. 2: Bearing almost out. Longitudinal movements, pad hanging over edge of bearing shelf, evident. Lateral movements evident from bearing / shims displacing and rotating relative to each other. 3: Bearing / shims slightly displaced relative to each other. 4: Bearing / shims displaced relative to each other. Bearing looks to be displaced longitudianlly with edge around extent of bearing shelf.
60052	42355	F			12.21	7.93		4.2	1: Bearing / shims displaced relative to each other. 2: Bearing / shims displaced relative to each other. 3: No photo (Slab Interface). 4: No photo (Slab Interface).
60052	42355	T	4.98	4.21			5.9		1: Bearing / shims slightly displaced relative to each other. 2: Bearing / shims displaced relative to each other. 3: No photo (Slab Interface). 4: No photo (Slab Interface).
60262	42355	F			22.8	19.42	4.5		1: Bearing and/or shims coming out. Bearing has displaced laterally to inner face ofguideway beam / back of lateral restraint bracket. 2: Bearing / shims slightly displaced relative to each other. 3: Bearing / shims slightly displaced relative to each other. 4: Bearing / shims slightly displaced relative to each other.
60272	42355	F			19.33	26.84		3.3	1: Bearing / shims displaced relative to each other. 2: Bearing/shims displaced significantly relative to each other (circa 200mm or more) 3: Bearing and shims displaced realtive to each other. Edge of bearing slightly projecting over edge of bearing shelf. 4: Bearing and shims reasonably aligned, little relative displcament. Whole assembly seems to be at edge of bearing shelf.

INVESTIGATION F SUMMARY



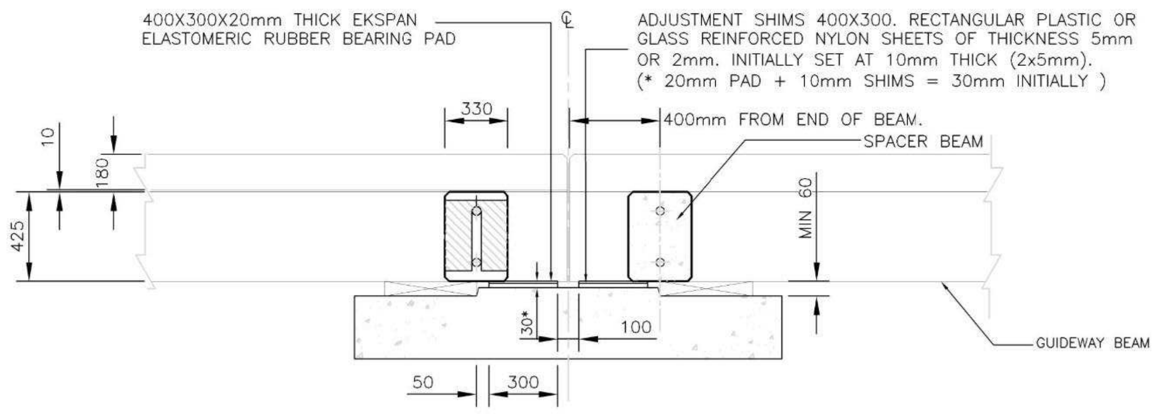
File name of photograph takes the form ch[chainage]_[Direction]_[Bearing Number].jpg

Chainage	Date	TO/ FROM	Steps 6-5 mm Outer To Camb	Steps 8-7 mm Inner To Camb	Steps 6-5 mm Inner From Camb	Steps 8-7 mm Outer From Camb	Inv C mm Outer	Inv C mm Inner	Comments on F1 Photographs 2-4 is Outer Beam; 1-3 is Inner Beam to Cambridge 2-4 is Inner Beam; 1-3 is Outer Beam from Cambridge
60292	42355	F			20.21	24.52		3.3	1: Bearing / shims displaced relative to each other. 2: Shims and bearing significantly displaced relative to each other. Movement looks to be laterally. 3: Bearing / shims look to be aligned, no obvious or discernable displacement. Whole arrangement looks to be at edge of bearing shelf. 4: Bearing / shims slightly displaced relative to each other. Shims and bearing oversailing edge of bearing shelf.
60512	42355	F			35.28	26.59	6.4	8.9	1: No photo (Slab Interface) 2: No photo (Slab Interface) 3: Bearing / shims slightly displaced relative to each other. 4: Bearing / shims slightly displaced relative to each other. Bearings and shims look to be out of position longitudinally towards edge of bearing shelf.
60512	42355	T	14.55	27.59			11.7	4.3	1: No photo (Slab Interface) 2: No photo (Slab Interface) 3: Bearing / shims slightly displaced relative to each other. 4: No shims?

Blank for double-sided printing

APPENDIX F – PROBABLE MECHANISM FOR ‘WALKING’ OF BEARINGS

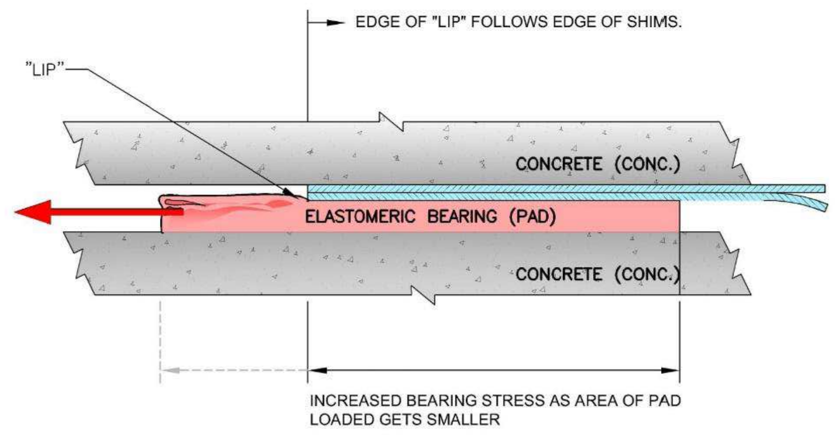
Blank for double-sided printing



TYPICAL INITIAL INTENDED CONSTRUCTION DETAIL (BEAM 1) BEARING AND BEARING SHIMS DETAIL AT JOINTS

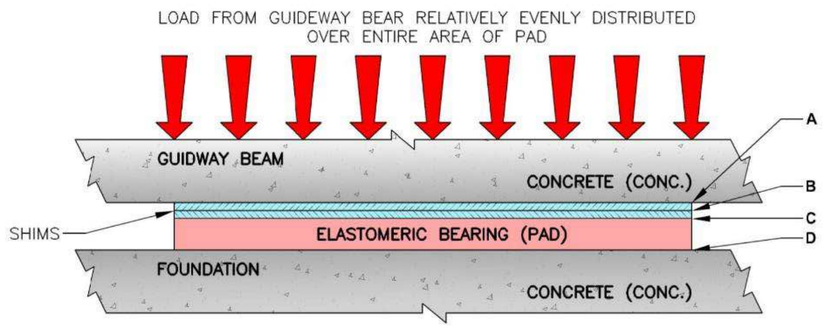
SCALE 1:25

3. THERMAL MOVEMENT CAUSES BEARING PAD TO MOVE TO LEFT.



NOTE:
AS THE SHIMS PROGRESSIVELY MOVE OUT THE "LIP" WILL FOLLOW. HEIGHT OF LIP WILL PROBABLY INCREASE AS THE AREA OF SHIM TO BEARING PAD CONTACT BECOMES LESS AND THE BEARING PAD STRESS IS INCREASED. THE LARGER STRESS WOULD TYPICALLY CAUSE A GREATER COMPRESSION (SQUASHING)OF THE PAD.

1. INITIALLY, AS INTENDED, BEARING PAD AND SHIMS ALL ALIGHNED



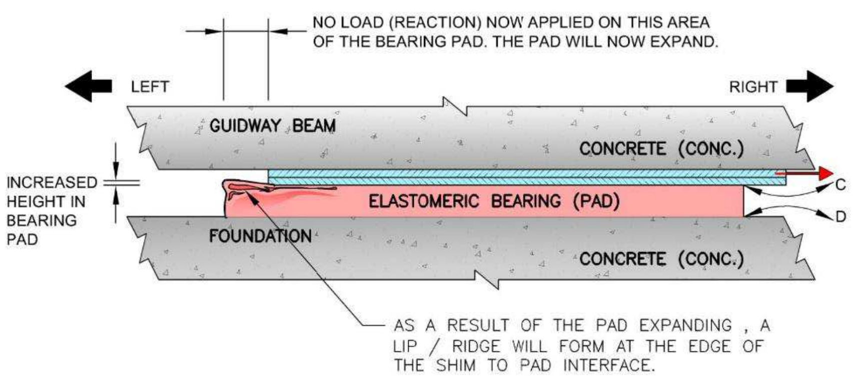
COEFFICIENTS OF FRICTION (μ).
FROM TEST'S AND USING VALUES FOR USED SHIMS AND WET CONDITIONS.

	INTERFACE	COEFFICIENT OF FRICTION		CONDITION
		RANGE	AVE.	
A	CONC. - SHIM	0.40 TO 0.60	0.46	WET
B	SHIM - SHIM	0.34 TO 0.51	0.40	WET
C	SHIM - PAD	0.32 TO 0.41	0.36	WET
D	PAD - CONC.	0.27 TO 0.37	0.32	WET
A	CONC. - SHIM	0.43 TO 0.53	0.48	DRY
B	SHIM - SHIM	0.26 TO 0.45	0.36	DRY
C	SHIM - PAD	0.37 TO 0.54	0.43	DRY
D	PAD - CONC.	0.27 TO 0.59	0.31	DRY

NOTE:
THE INTENDED CONSTRUCTION DETAIL IS TO INITIALLY HAVE THE SHIMS AND BEARING PAD ALIGNED. THIS RESULTS IN A RELATIVELY UNIFORM DISTRIBUTION OF LOAD ACROSS THE BEARING PAD. THE COMPRESSION (SQUASHING) OF THE PAD WOULD THEN BE SIMILAR OVER ITS ENTIRE AREA.

THIS IS ONE EXAMPLE BY WHICH THE BEARING CAN WALK. DEPENDING ON THE RELATIVE COEFFICIENTS OF FRICTION , OTHER MECHANISM BY WHICH THE WAY THE BEARING AND / OR SHIMS "WALK" RELATIVE TO EACH OTHER CAN OCCUR.

2. THERMAL MOVEMENT CAUSES SHIMS TO MOVE TO THE RIGHT.



THIS EXAMPLE ASSUMES THAT THE COEFFICIENT OF FRICTION AT THE SHIM TO PAD INTERFACE (C) IS LESS THAN THAT AT PAD TO FOUNDATION CONCRETE (D). SLIPPING COULD THEN OCCUR AT THIS INTERFACE IF THIS GUIDEWAY BEAM EXPANDS (OR CONTRACTS) SUFFICIENTLY TO THE RIGHT.
IF THE RESISTANCE OF THE SAME INTERFACE (C + LIP) IS THEN GREATER THAN THE RESISTANCE AT INTERFACE D , THEN SLIPPING WILL THEN OCCUR AT THIS LOWER INTERFACE OF PAD TO FOUNDATION CONCRETE AS THE BEAM CONTRACTS (OR EXPANDS) TO THE LEFT. THUS THERMAL MOVEMENTS RESULT, BECAUSE OF THE RESISTANCE OF A LIP , IN WALKING OF THE BEARING PAD IN ONE DIRECTION ONLY.

NOTE:
AS A RESULT OF EXTERNAL INFLUENCES (THERMAL EFFECTS , BUS TRAFFICKING, FOUNDATION / GROUND MOVEMENTS FOR EXAMPLE) THE SHIMS AND BEARING BECOME DISPLACED RELATIVE TO EACH OTHER.

PROBABLE MECHANISM FOR 'WALKING' OF BEARING AND / OR SHIMS

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APPENDIX G – INVESTIGATION E CHARTS

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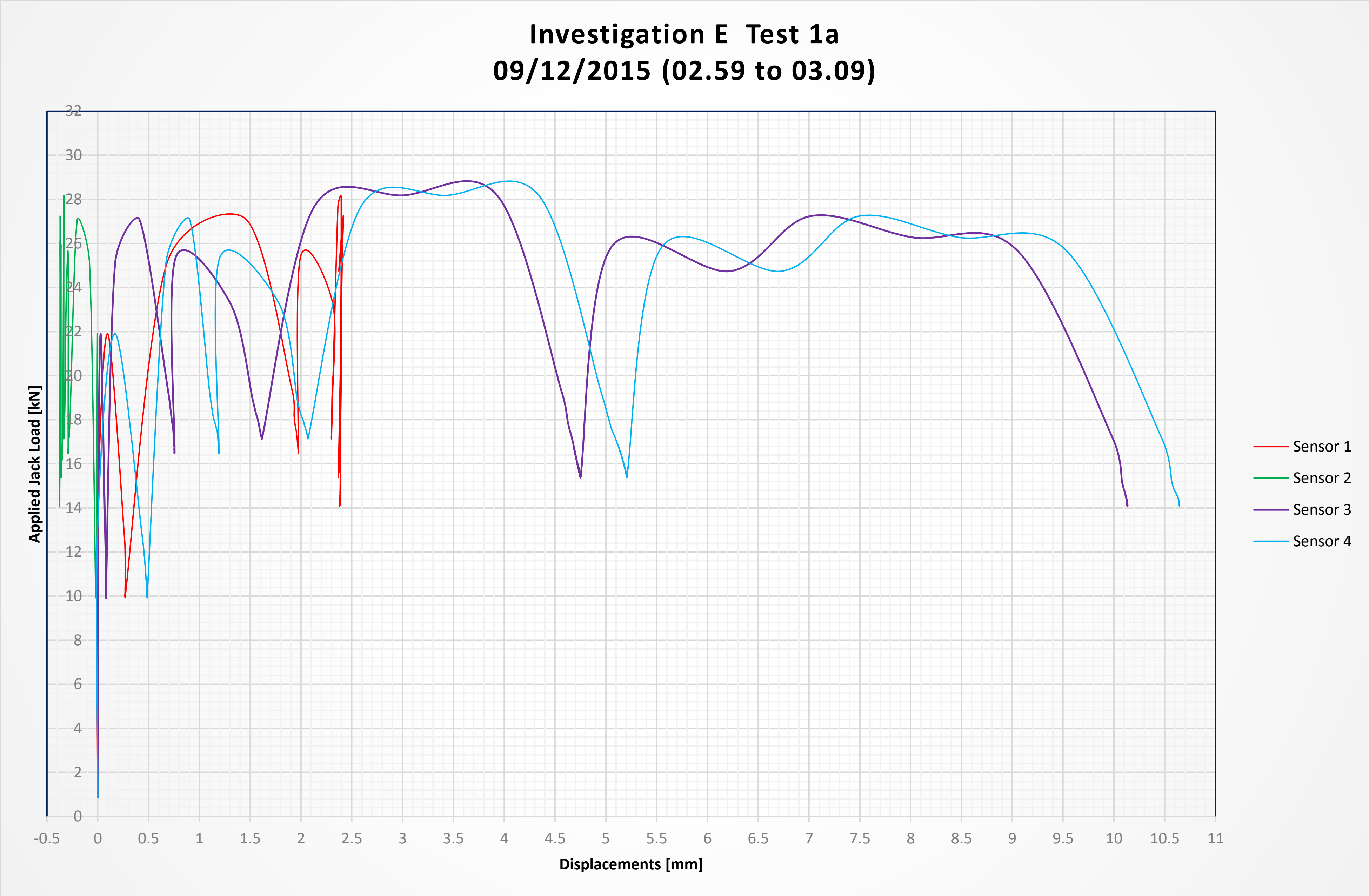
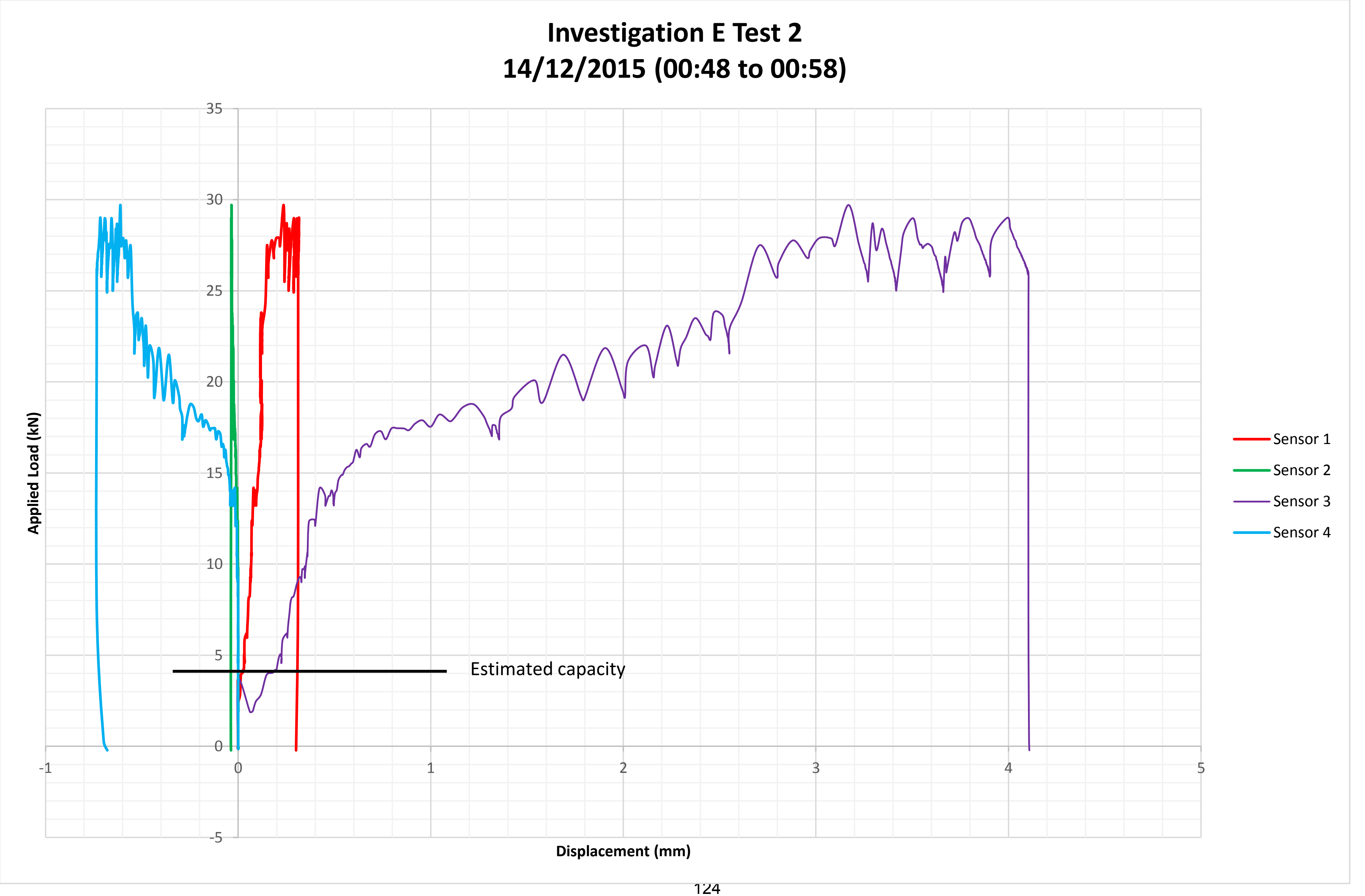
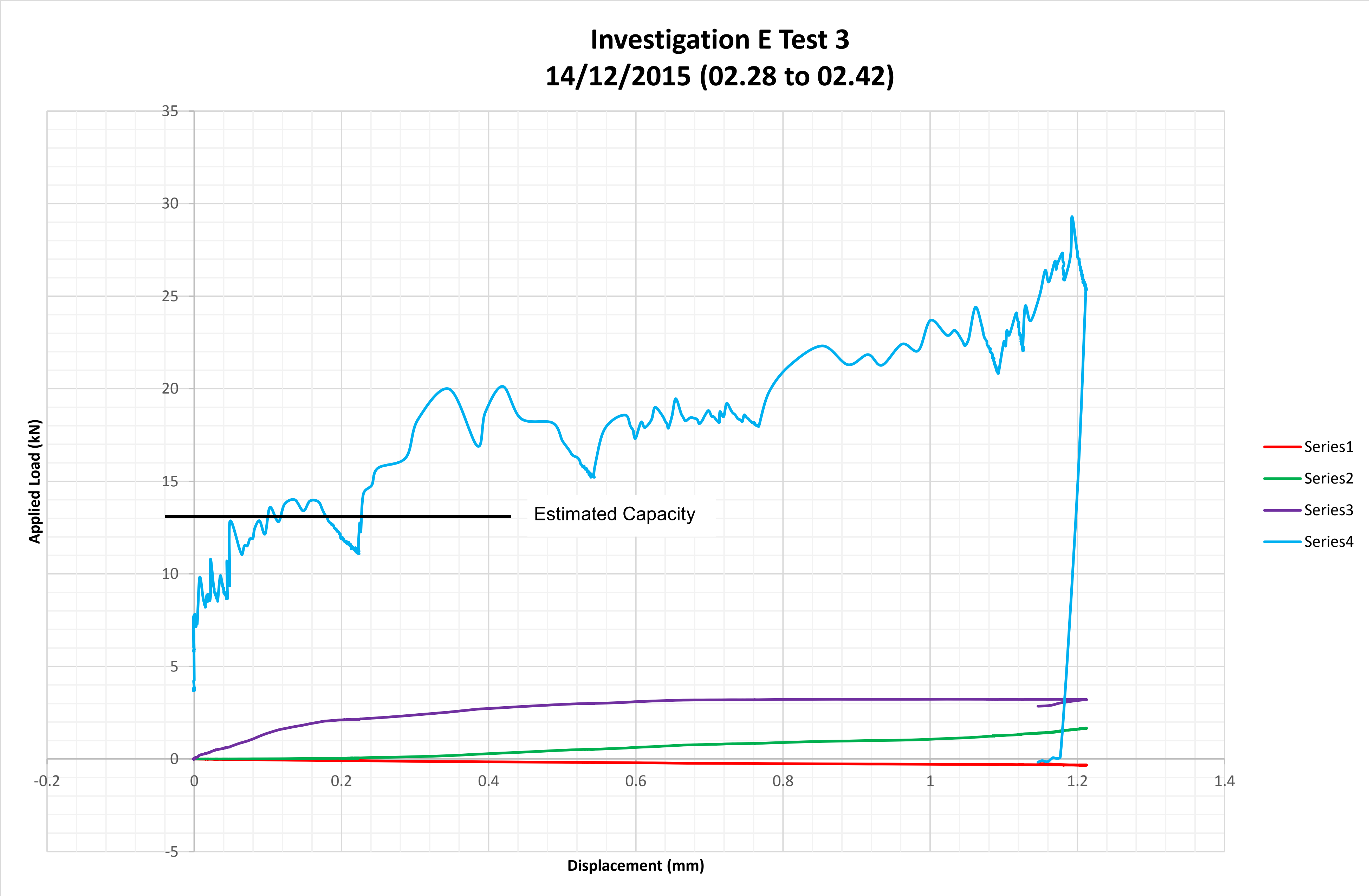
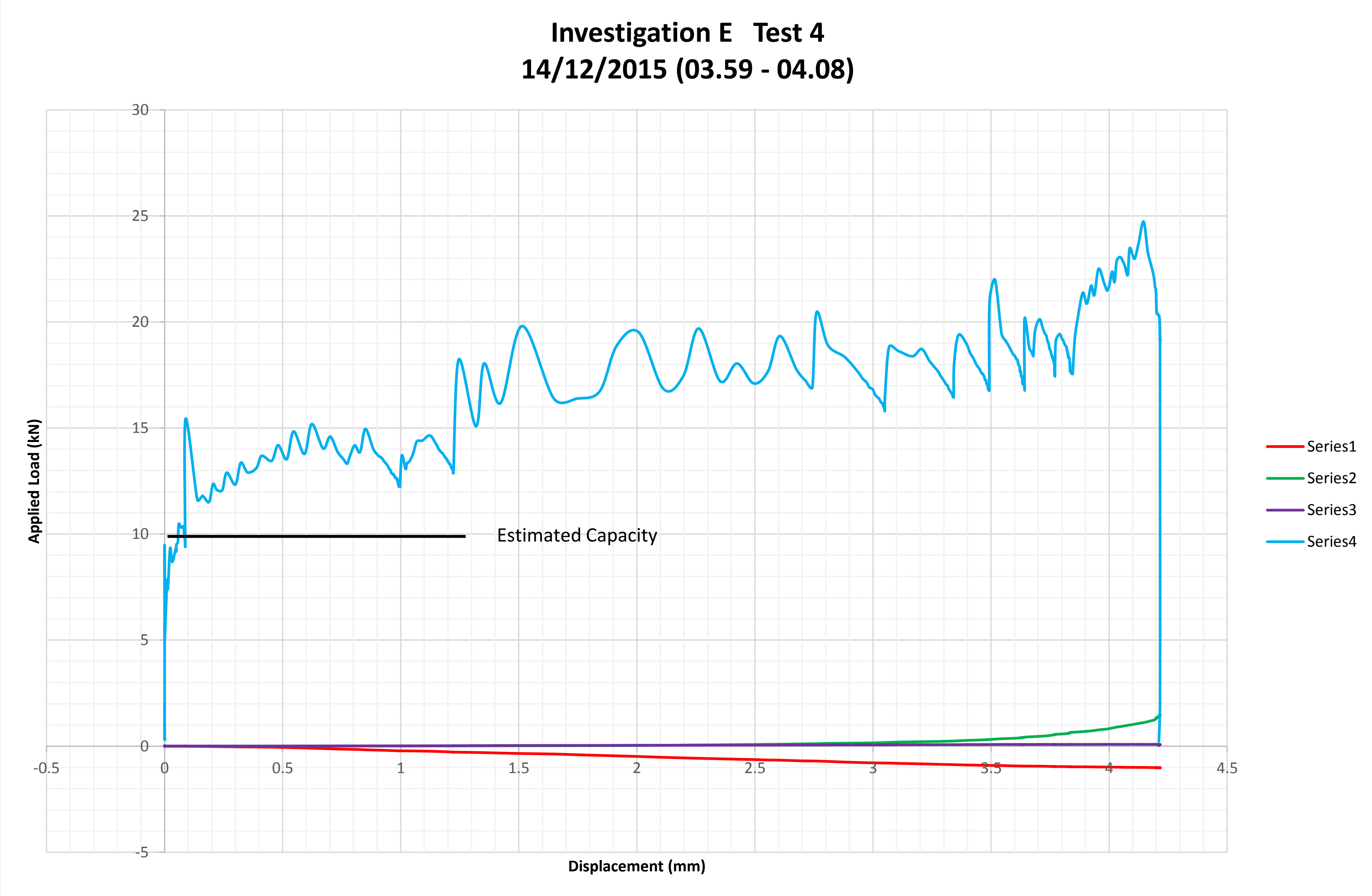
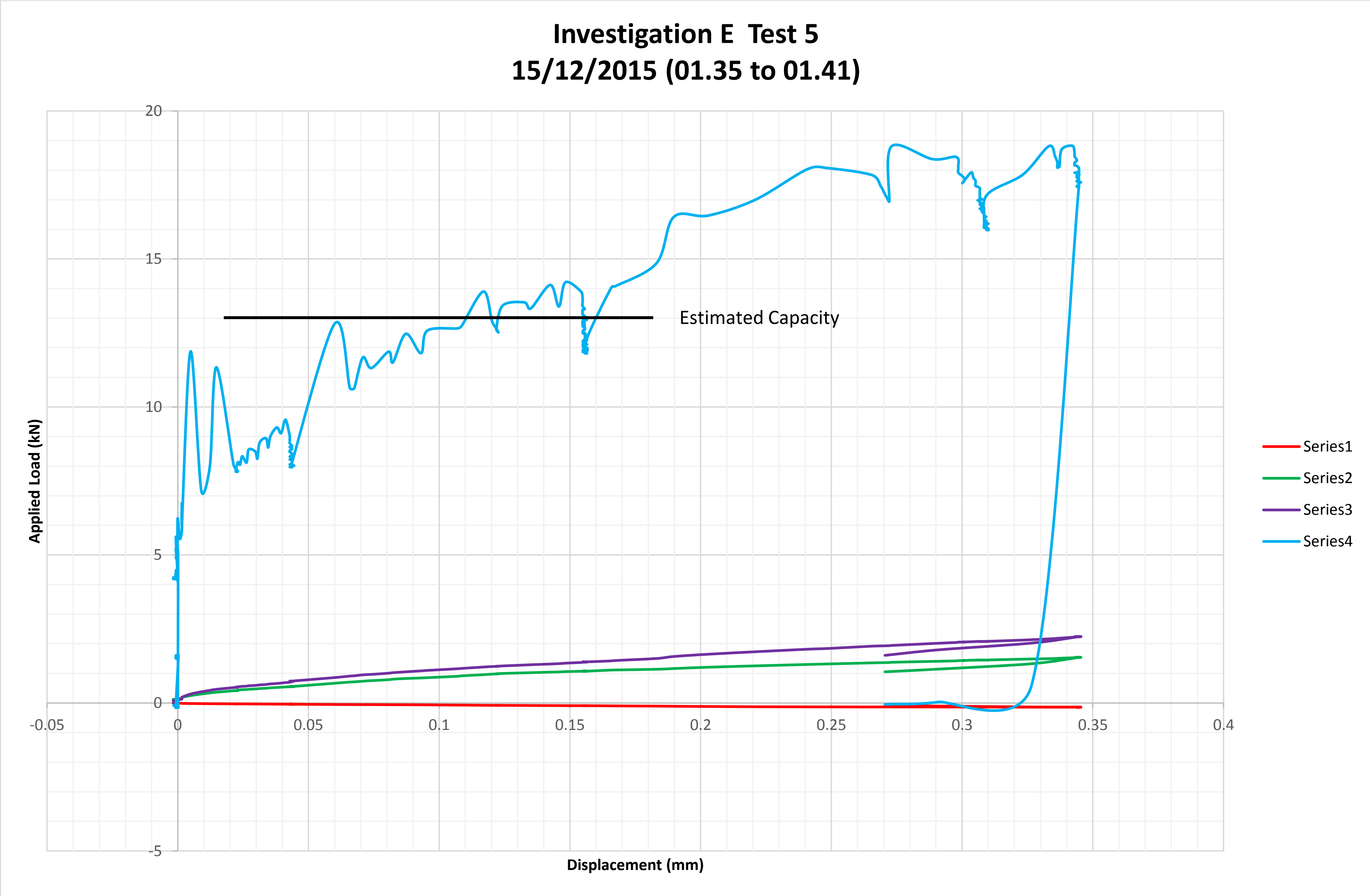
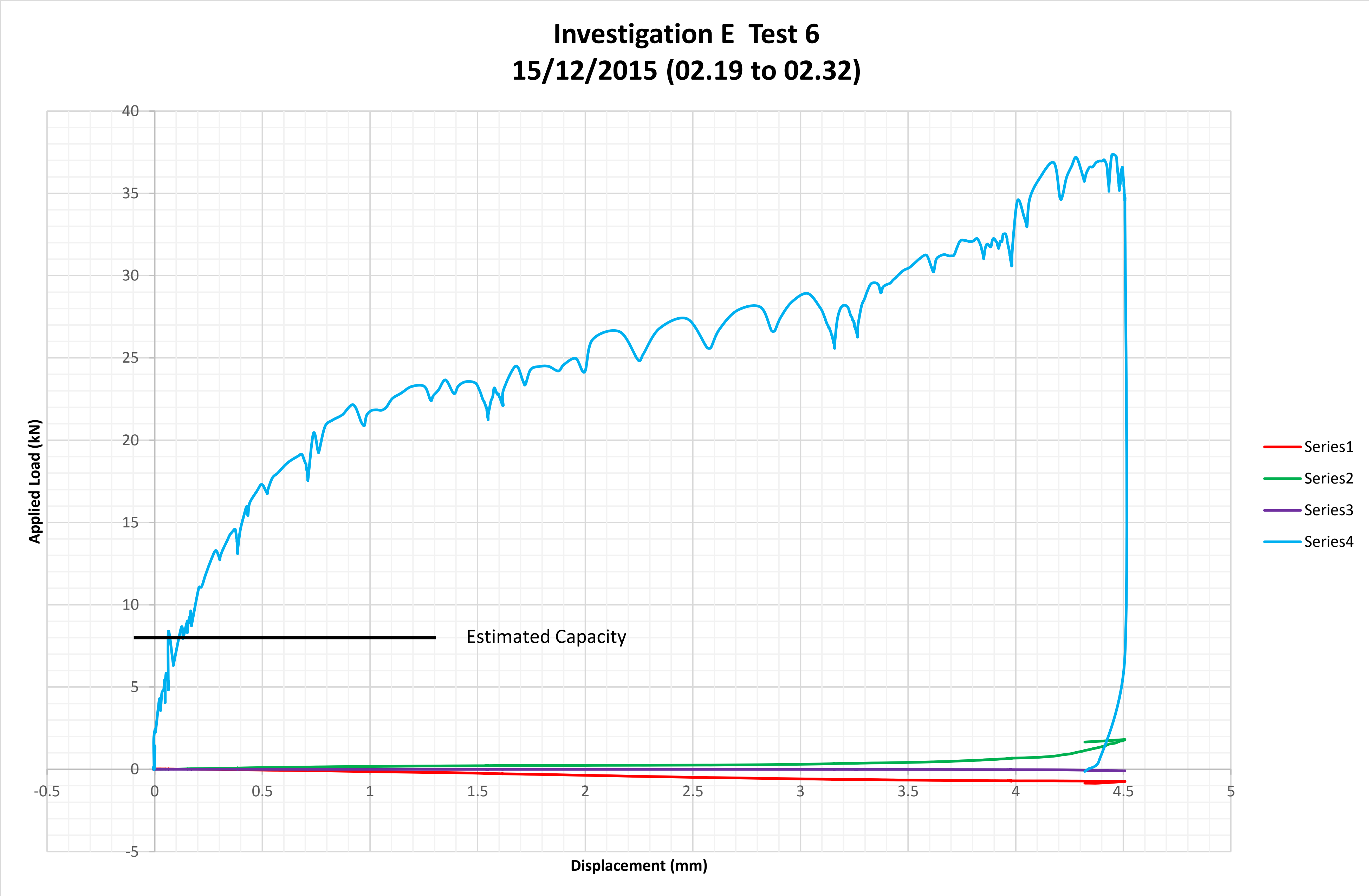

Investigation E Test 1a
09/12/2015 (02.59 to 03.09)
Applied Jack Load [kN]
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
11
Displacements [mm]
Sensor 1
Sensor 2
Sensor 3
Sensor 4

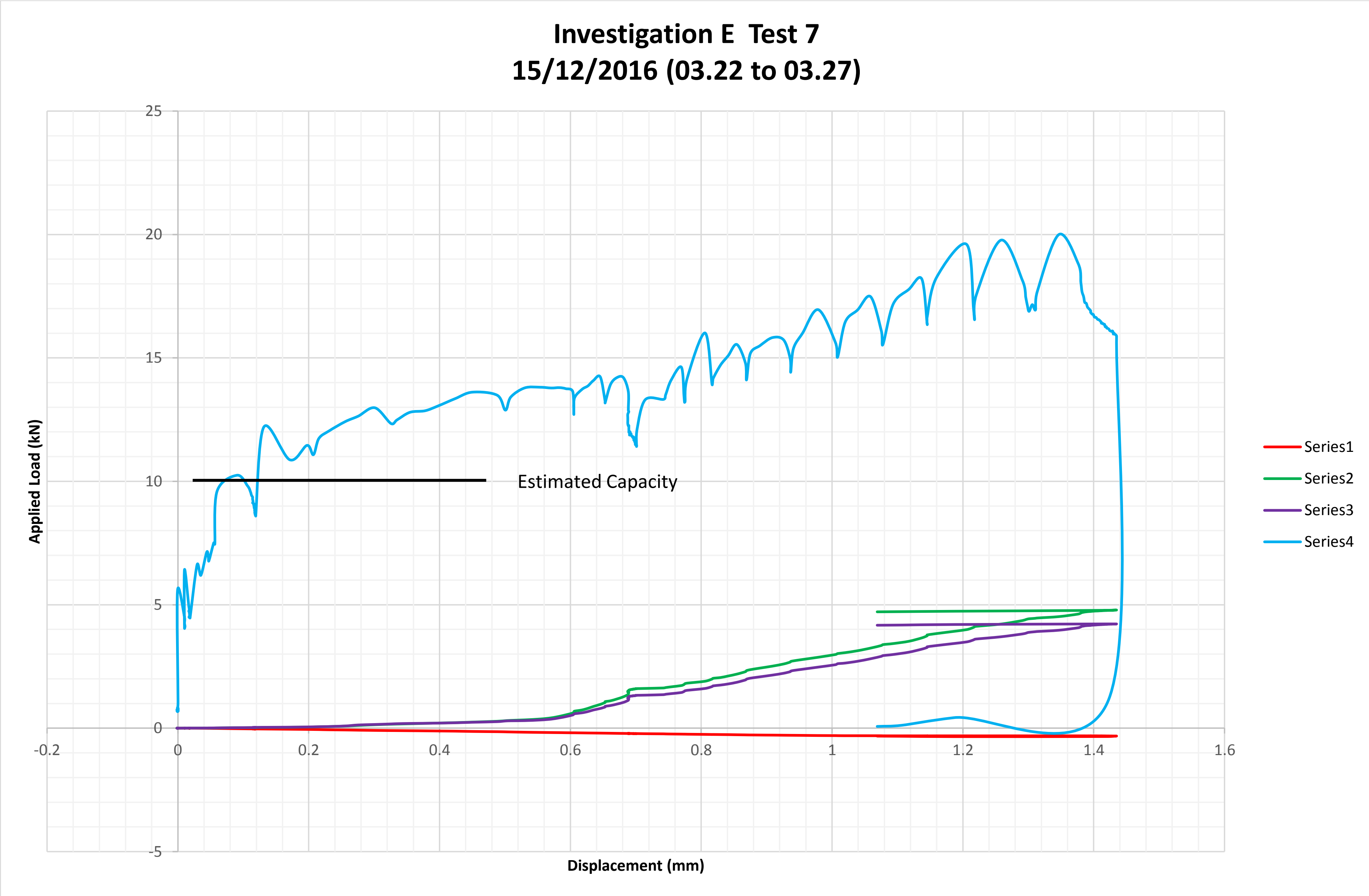

Investigation E Test 2
14/12/2015 (00:48 to 00:58)
Applied Load (kN)
35
30
25
20
15
10
5
0
-5
-1
0
1
2
3
4
5
Displacement (mm)
Estimated capacity
Sensor 1
Sensor 2
Sensor 3
Sensor 4

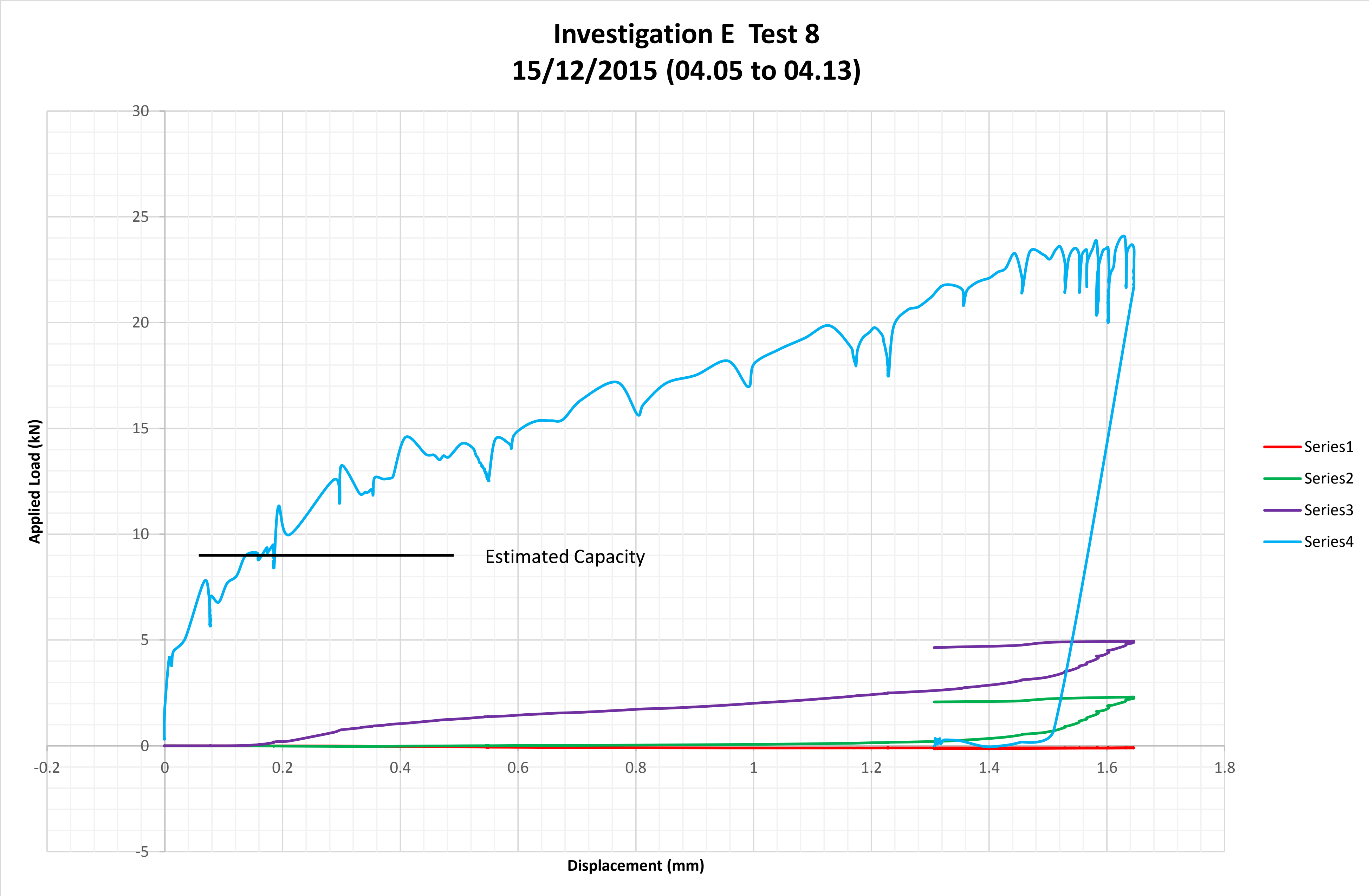

Investigation E Test 3
14/12/2015 (02.28 to 02.42)
Applied Load (kN)
35
30
25
20
15
10
5
0
-5
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Estimated Capacity
Displacement (mm)
Series1
Series2
Series3
Series4


Investigation E Test 4
14/12/2015 (03.59 - 04.08)
Applied Load (kN)
30
25
20
15
10
5
0
-5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Displacement (mm)
Estimated Capacity
Series1
Series2
Series3
Series4


Investigation E Test 5
15/12/2015 (01.35 to 01.41)
Applied Load (kN)
20
15
10
5
0
-5
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Displacement (mm)
Estimated Capacity
Series1
Series2
Series3
Series4


Investigation E Test 6
15/12/2015 (02.19 to 02.32)
40
35
30
25
20
15
10
5
0
-5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Applied Load (kN)
Displacement (mm)
Estimated Capacity
Series1
Series2
Series3
Series4


Investigation E Test 7
15/12/2016 (03.22 to 03.27)
Applied Load (kN)
25
20
15
10
5
0
-5
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Displacement (mm)
Estimated Capacity
Series1
Series2
Series3
Series4


Investigation E Test 8
15/12/2015 (04.05 to 04.13)
Applied Load (kN)
30
25
20
15
10
5
0
-5
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Displacement (mm)
Estimated Capacity
Series1
Series2
Series3
Series4

APPENDIX H – INDICATIVE REMEDIAL MEASURES

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1. WHOLE OF LADDER ASSEMBLY TO BE FULLY EXCAVATED SUCH THAT ALL THE STRUCTURE, BRACKETS ETC ARE FULLY EXPOSED. THIS MAY ALSO REQUIRE REMOVAL OF CONCRETE KERBING WHERE ADJACENT TO PLATFORMS AND/OR MAINTENANCE TRACK. ALL MATERIALS TO BE SET ASIDE FOR RE-USE UNLESS AGREED OTHERWISE IN ADVANCE.
2. LADDER TO BE RAISED SUCH THAT:
   A. ACCESS TO ALL BEARINGS AND SHIMS IS PROVIDED
   B: ACCESS TO ALL THE TENSIONED BOLTS CAN BE MADE TO ENABLE THE LADDER TO BE TAKEN APART AND SUBSEQUENTLY RE-ASSEMBLED.
3. BEARING PADS AND SHIMS, REMOVED, CLEANED AND SET ASIDE FOR RE-USE. ANY DAMAGED ITEMS SHOULD BE REPLACED.
4. THE TENSION IS TO BE CAREFULLY RELEASED, THE SPACERBEAMS REMOVED, AND ALL ITEMS SET ASIDE FOR RE-USE. ANY DAMAGED ITEMS SHOULD BE MADE GOOD OR REPLACED.
5. TOP OF CONCRETE AND UNDERSIDE OF GUIDE BEAMS, AT ALL BEARING POSITIONS TO BE CLEANED SUCH THAT ALL LOOSE DEBRIS AND DETRITUS IS REMOVED AND CLEAN CONCRETE SURFACES ARE PRESENTED.CONSIDERATION TO BE GIVEN TO ROUGHENING CONCRETE CONTACT SURFACE ON THE BOTTOM OF THE BEAM TO IMPROVE FRICTION
6. HOLES TO BE CORED ,TOP TO BOTTOM, THROUGH EACH END OF THE GUIDE BEAMS ON EACH SIDE, FOUR NUMBER HOLES PER LADDER ASSEMBLY, CORE TO CONTINUE 75MM INTO TOP OF FOUNDATION AT CENTRE OF INTENDED BEARING LOCATION.
7. EACH SHIM AND BEARING PAD TO ALSO HAVE HOLE CAREFULLY DRILLED THROUGH IT AT CENTRE, IN ACCORDANCE WITH ANY MANUFACTURERS RESTRICTIONS AND REQUIREMENTS.
8. STUD TO BE LOWERED DOWN THROUGH HOLES, USING "T-BAR" OR SIMILAR , AND THREADED COUPLER TO FACILITATE. APPROPRIATE LEVELLING SHIMS AND ELASTOMERIC BEARING TO BE ALIGNED SUCH THAT STUD PASSES THROUGH CENTRAL HOLE AND DOWN INTO HOLE FORMED IN TOP OF FOUNDATION.
9. ELASTOMERIC PAD TO BE BONDED TO TOP OF CONCRETE FOUNDATION IN ACCORDANCE WITH THE MANUFACTURER REQUIREMENTS AND SPECIFICATION.
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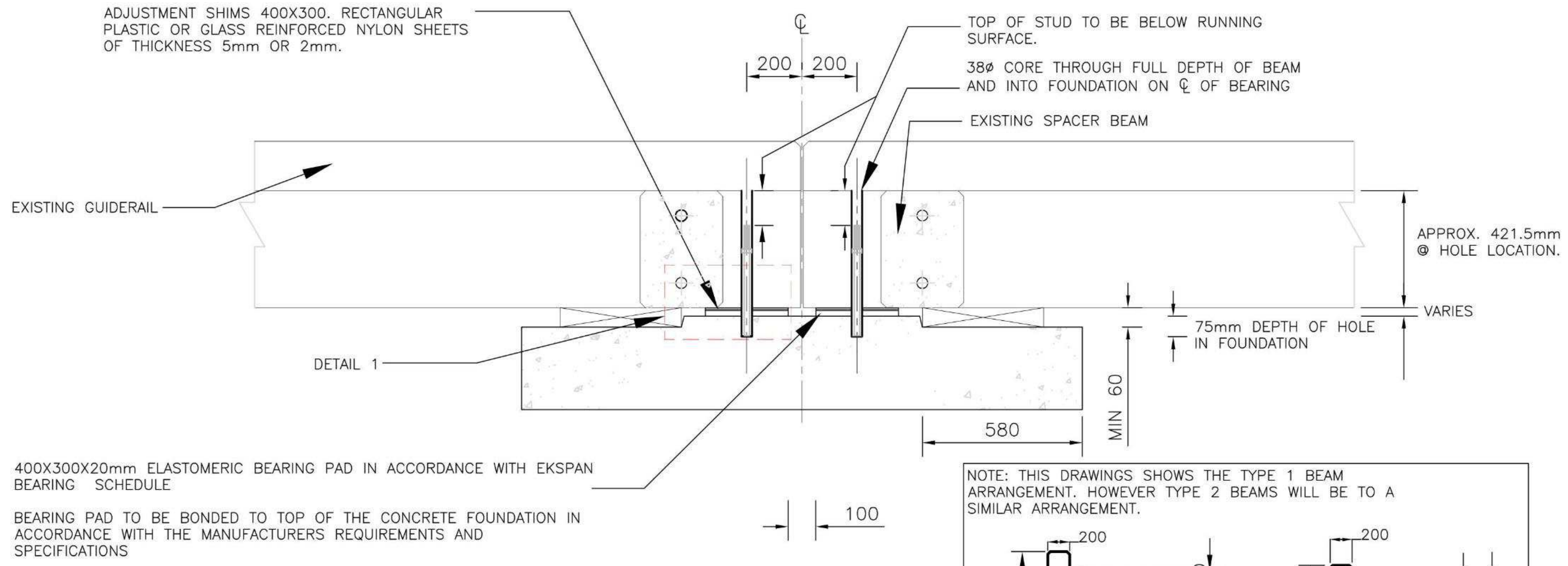
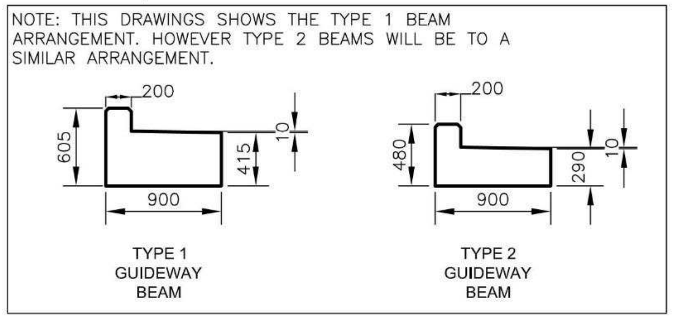
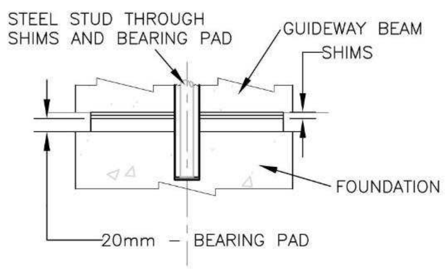
11. ONCE LEVELLED, BUNG HOLES IN RUNNING SURFACE.
12. THE FINAL ORDER OF OPERATIONS TO BE DISCUSSED AND AGREED WITH CONTRACTOR PRIOR TO COMMENCEMENT OF ANY WORKS.

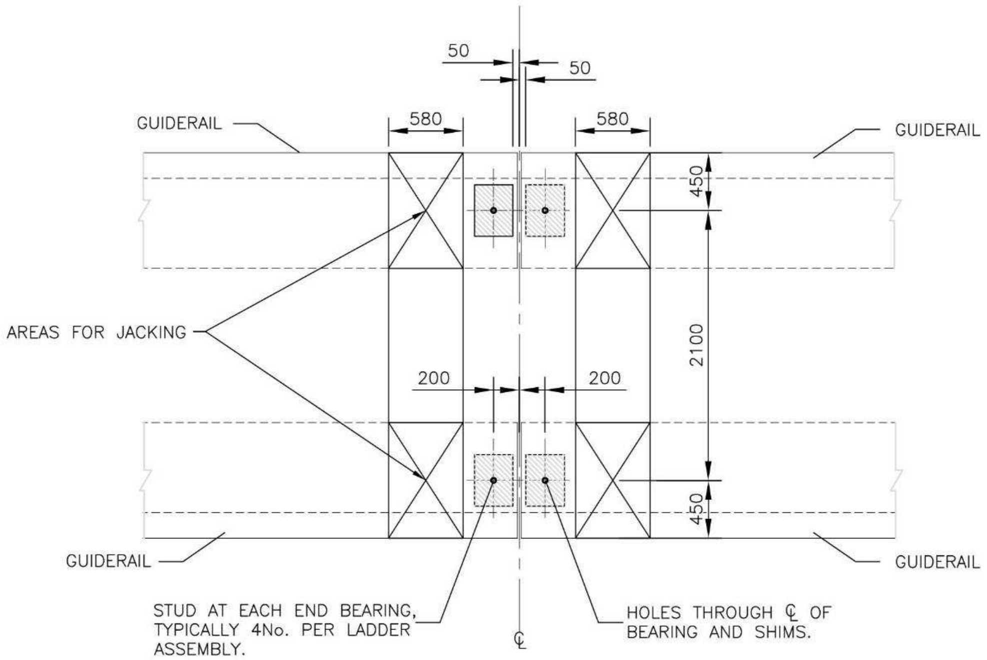




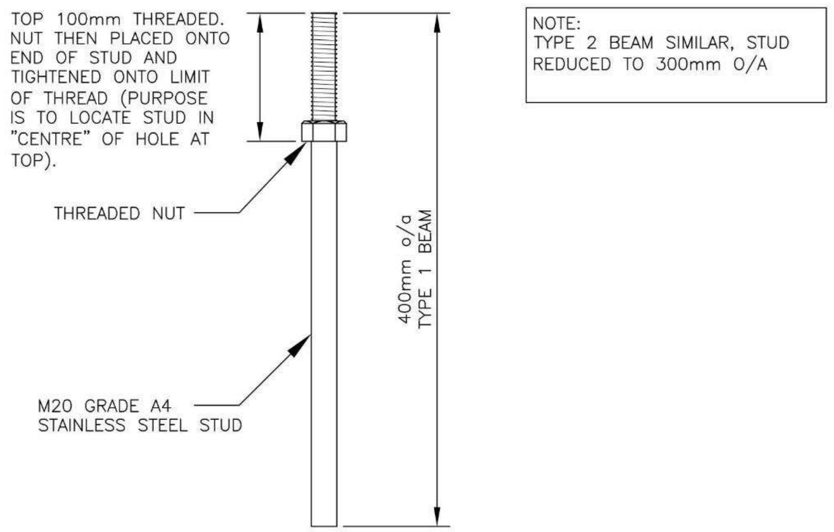
STAINLESS STEEL STUD TO HOLD SHIMS IN PLACE
SCALE 1:20



DETAIL 1
SCALE 1:10



PLAN ON BEARINGS
SCALE 1:50



TYPICAL STAINLESS STEEL STUD ARRANGEMENT

SCALE 1:5

STUD INTO FOUNDATION - REQUIRED AT ALL END BEARINGS , THAT IS BOTH "FIXED" AND "FREE" JOINT LOCATIONS

TYPE 1 BEAMS

(TYPE 2 BEAMS SIMILAR)

DRAWING 1 - PROVIDING BEARING/SHIM RESTRAINT - SHEET 1 OF 3

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11. ONCE LEVELLED, BUNG HOLES IN RUNNING SURFACE.
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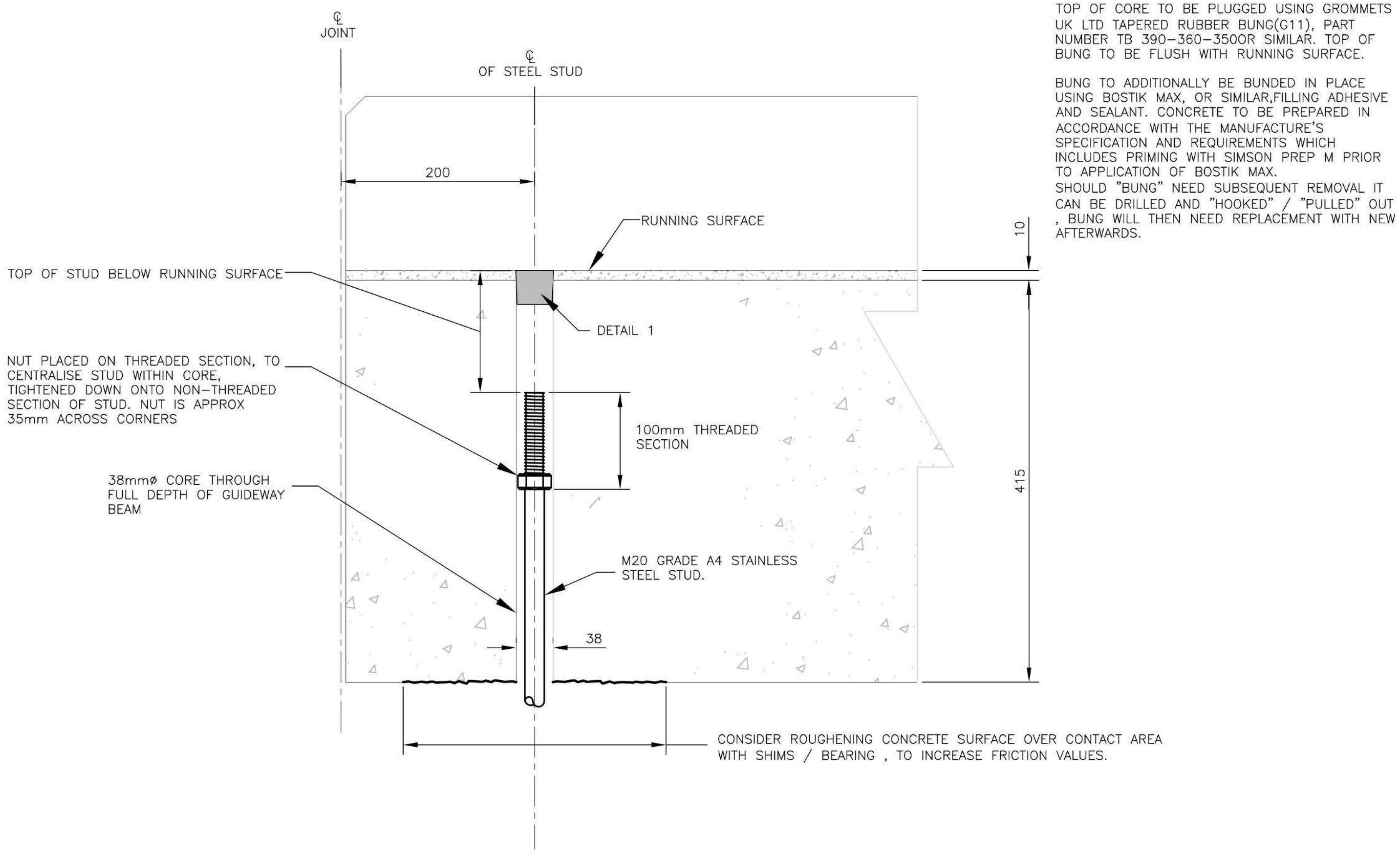

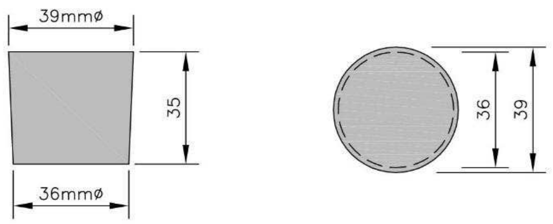

TOP OF DRILLED CORE TO BE PLUGGED WITH GROMMETS UK LTD TAPERED RUBBER BUNG(G11), PART NUMBER TB 390-360-350 OR SIMILAR.

DETAIL 1

SCALE: 1:2

STUD THROUGH GUIDEWAY BEAMS

TYPE 1 BEAMS

(TYPE 2 BEAMS SIMILAR)

DRAWING 2 - PROVIDING BEARING/SHIM RESTRAINT - SHEET 2 OF 3

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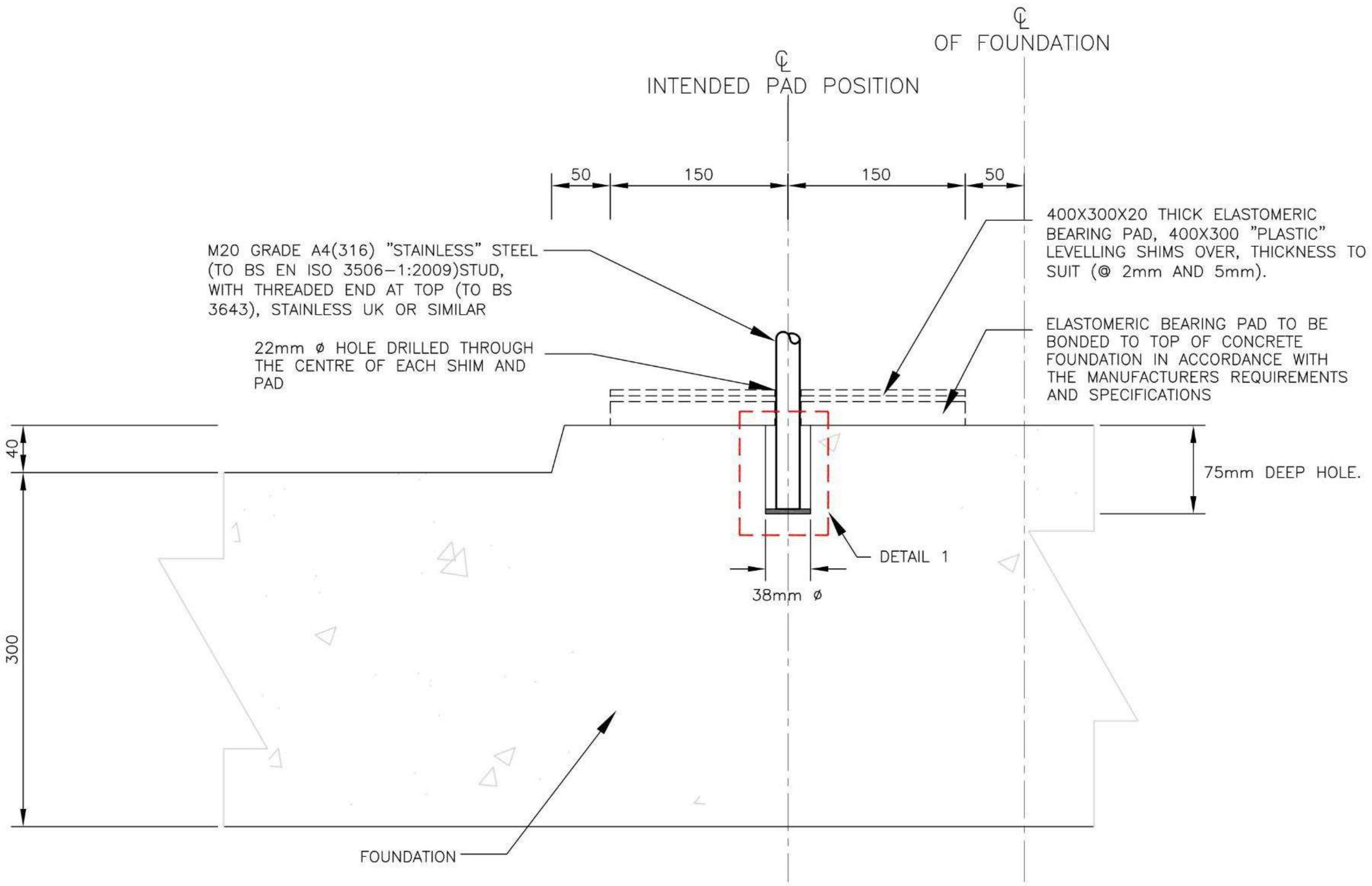
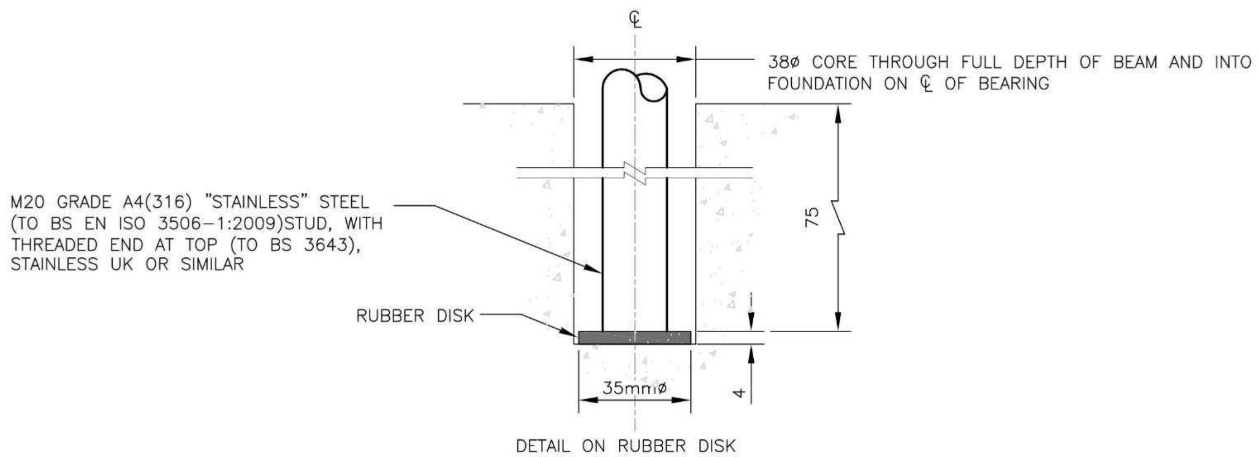


LONG SECTION ALONG FOUNDATION (PILE CAPS SIMILAR)

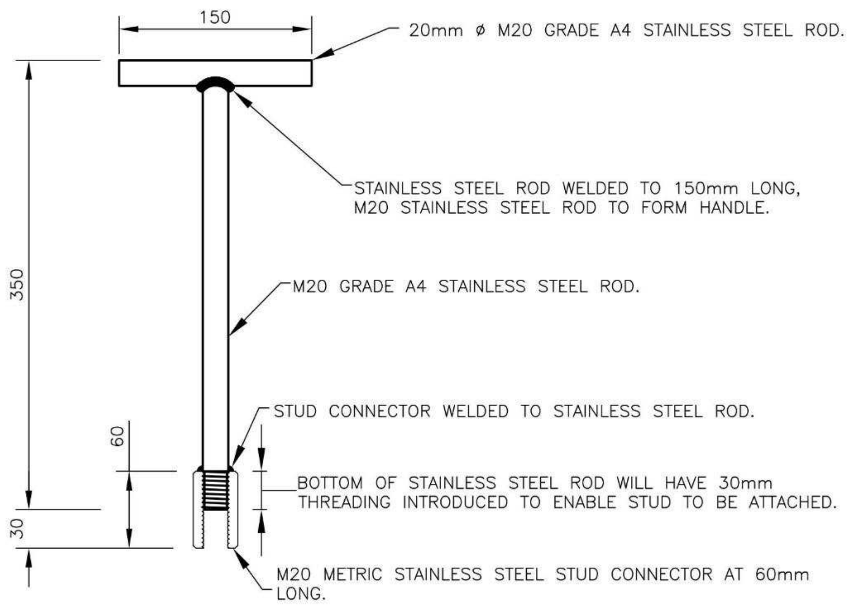
SCALE: 1:5



35mmø X 4mm THICK RUBBER DISK CAREFULLY PLACED INTO BOTTOM OF CORE HOLE PRIOR TO INSERTION OF STUD. RUBBER DISK BY GROMMETS LTD: CODE G36 PART No. RD350-40 OR SIMILAR APPROVED.

DETAIL 1

SCALE: 1:2



M20 STAINLESS STEEL STUD REMOVAL TOOL FOR BUDGET PRICING PURPOSES ONLY

STUD TO "HOLD" SHIMS AND BEARING IN PLACE

TYPE 1 BEAMS
(TYPE 2 BEAMS SIMILAR)

DRAWING 3 - PROVIDING BEARING/SHIM RESTRAINT - SHEET 3 OF 3

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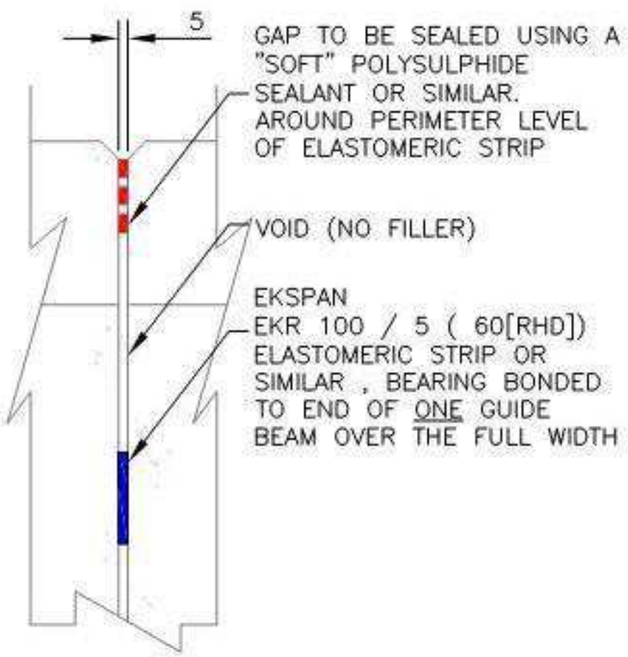
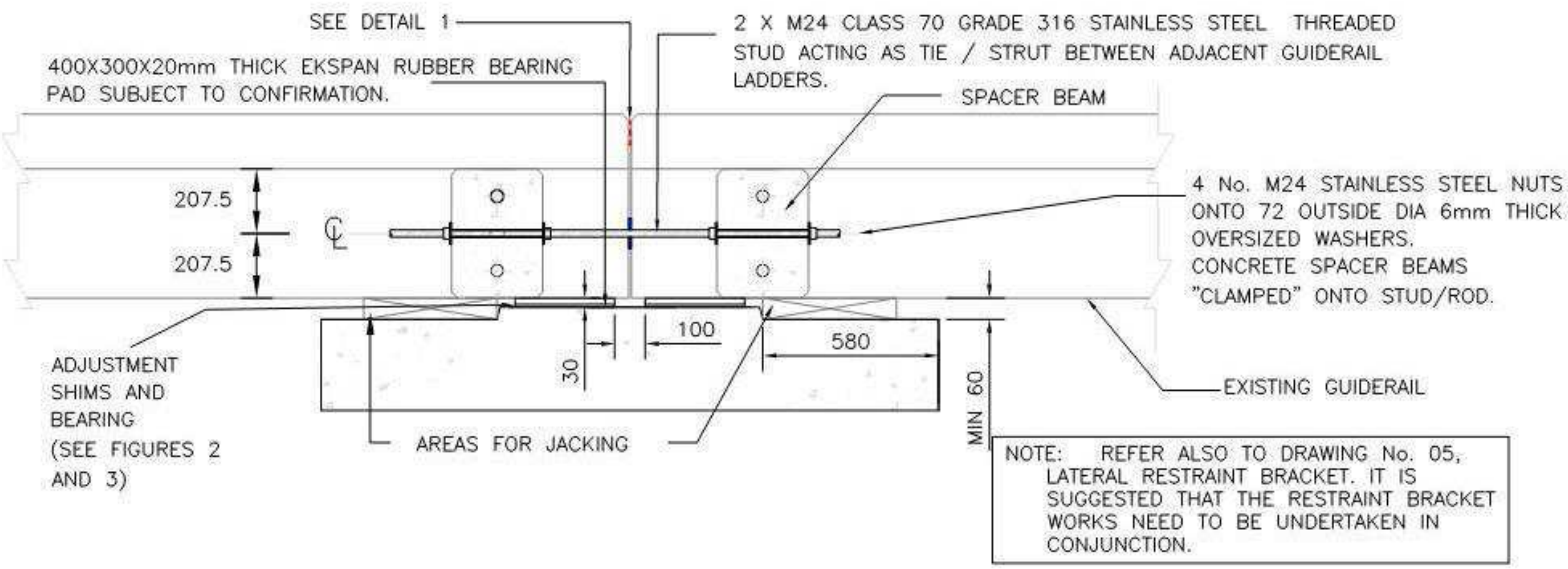
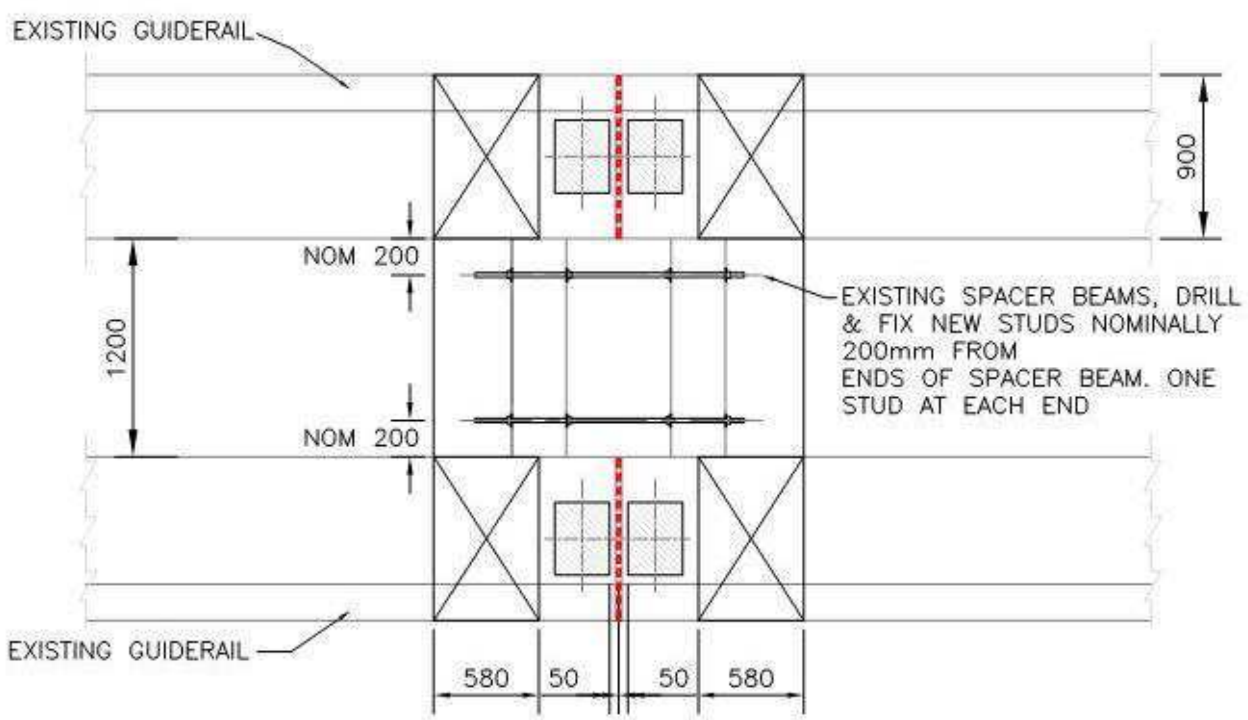


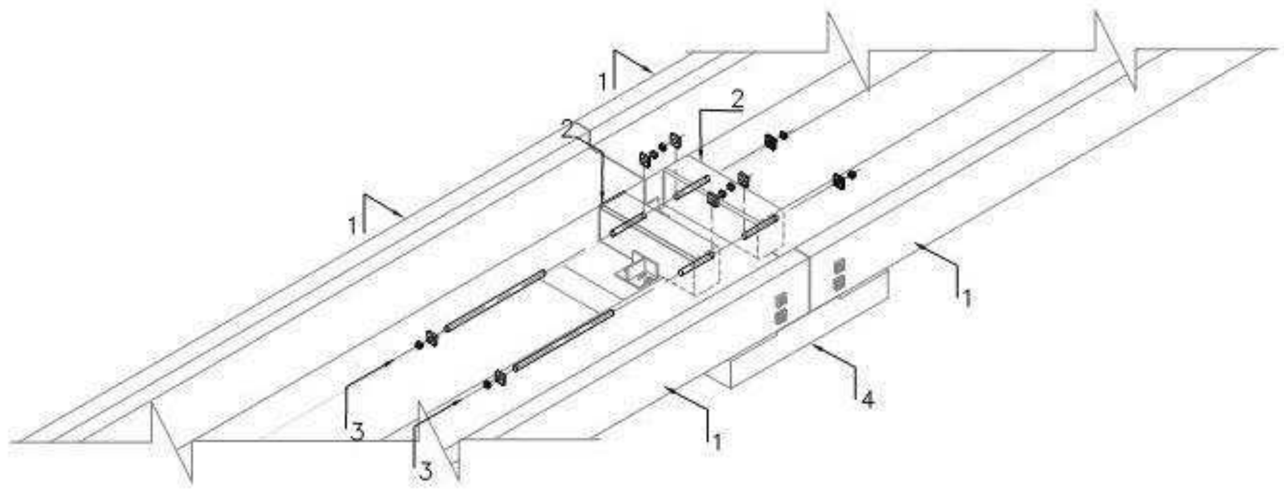
DETAIL 1: POLYSULPHIDE SEALANT ARRANGEMENT
SCALE 1:10



STRUT / TIE DETAIL AT "SO CALLED" FIXED JOINT
SCALE 1:25



PLAN ON BEARINGS
SCALE 1:50



EXPLODED ISOMETRIC VIEW AT "SO CALLED" FIXED JOINT

ITEM KEY
1: GUIDERAIL (EXISTING)
2: SPACER BEAMS (EXISTING)
3: THREADED STUD ACTING AS TIE/ STRUT BETWEEN ADJACENT GUIDERAIL LADDERS. (NEW)
4: FOUNDATION BASES (PILE CAPS SIMILAR) (EXISTING)

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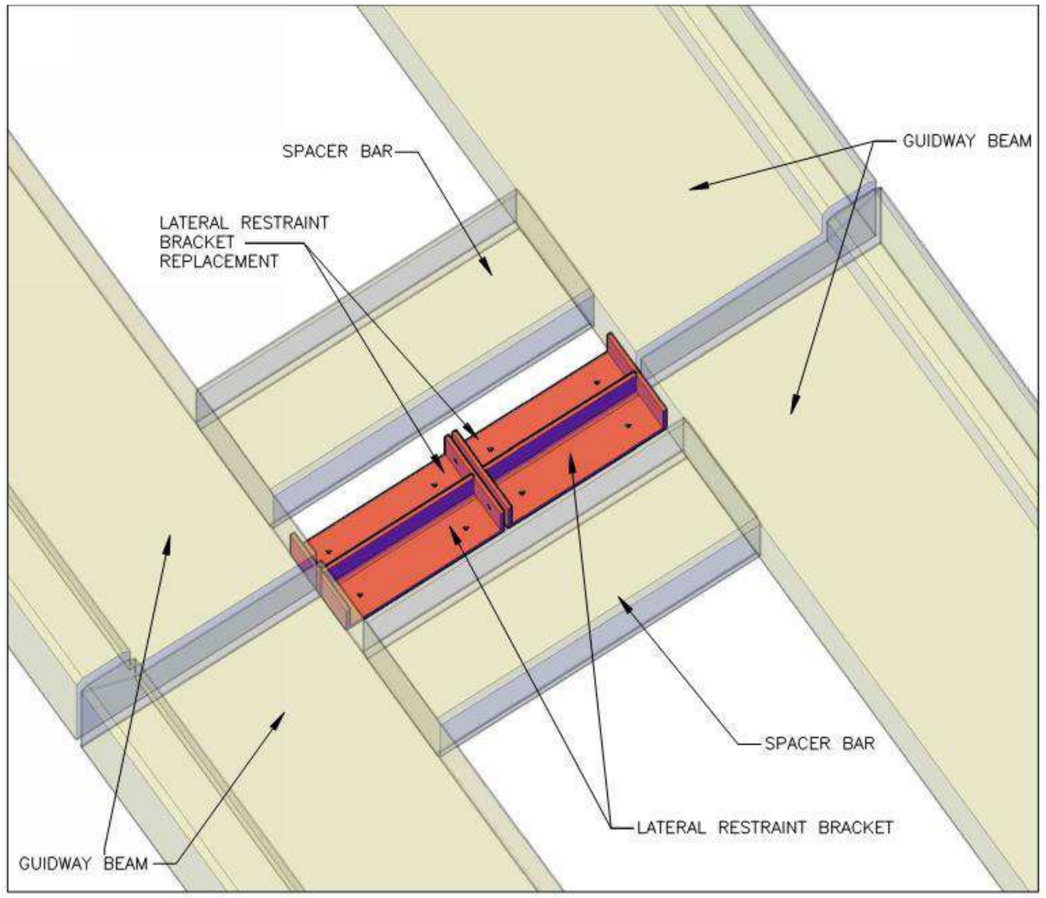
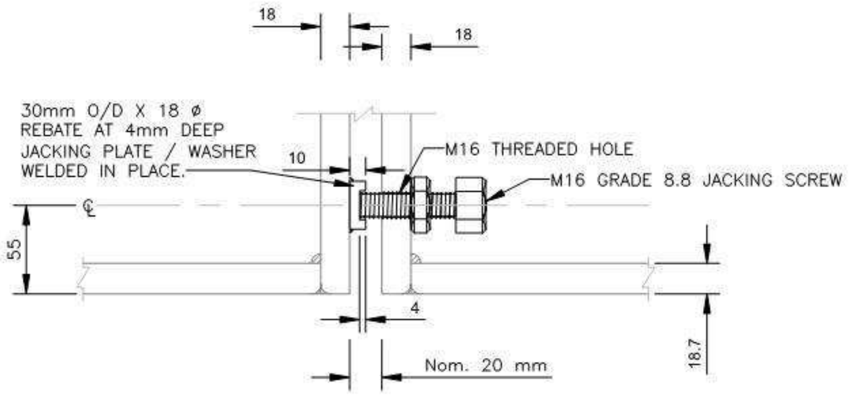
DRAWING 4: TIED JOINT DETAIL - STRUT/ TIE AT ALTERNATE JOINTS

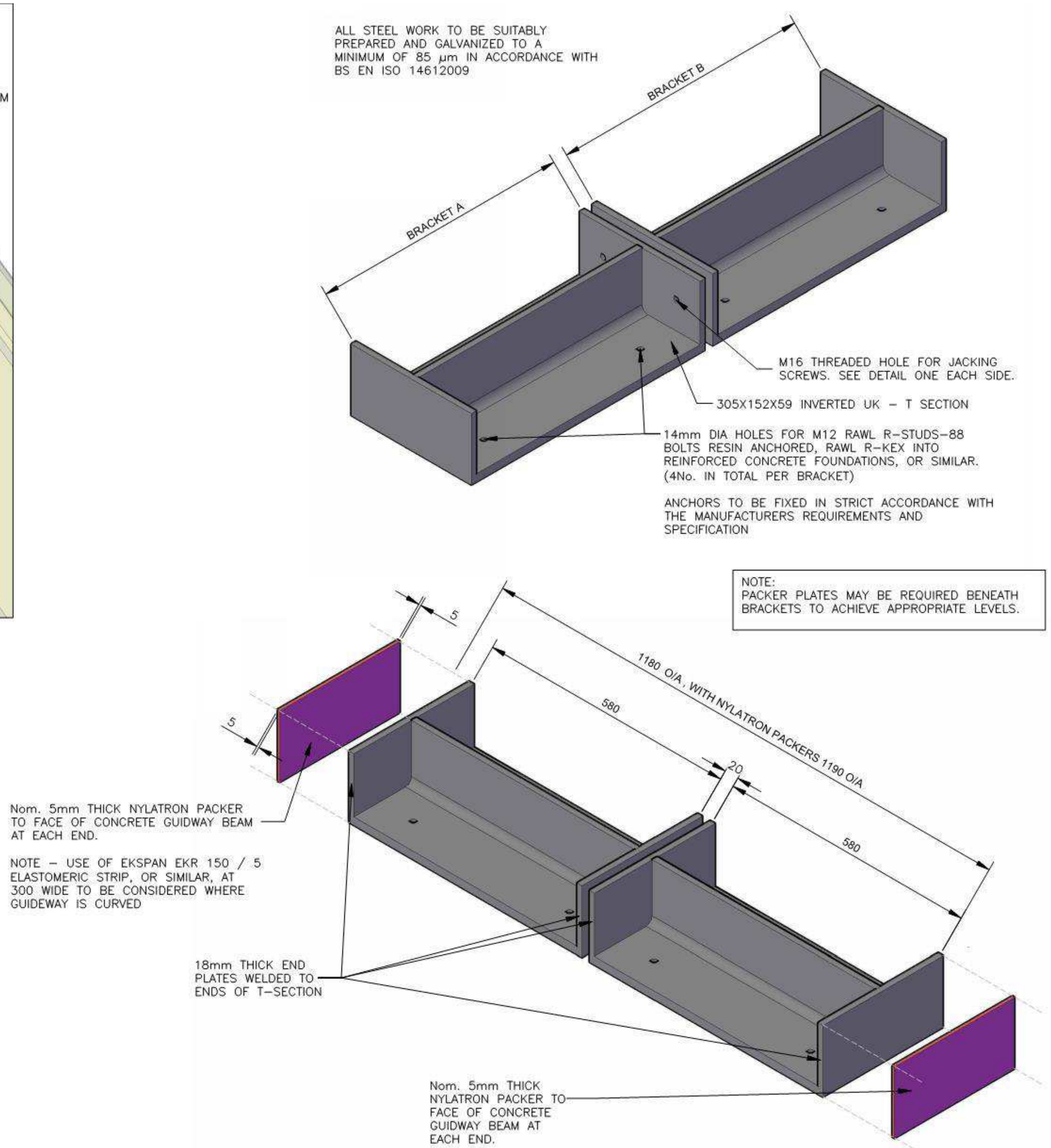
FOR BUDGET PRICING PURPOSES ONLY



INDICATIVE LOCATION OF LATERAL RESTRAINT BRACKET.
NOT TO SCALE



DETAIL 1 : JACKING SCREW AT "GAP"
NOT TO SCALE



DRAWING 5
LATERAL RESTRAINT BRACKET REPLACEMENT

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Capita Property and Infrastructure Ltd.

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GENERAL NOTES

1. ALL REPAIRS TO BE IN ACCORDANCE WITH BS EN 1504–3 CLASS R4.
2. UNRESTRAINED SURFACE AREA OF THE REPAIR MUST BE KEPT TO A MINIMUM.
3. DAMAGED/SPALLED CONCRETE TO BE CAREFULLY BROKEN BACK IN LINE WITH REPAIR MATERIAL SUPPLIER SPECIFICATION.
   AREA TO BE MADE GOOD USING FOSROC, RENDEROC LA55, OR SIMILAR.
4. CONTRACTOR IS TO SAW CUT OR CUT BACK THE EXTREMITIES OF THE REPAIR LOCATIONS TO A DEPTH OF AT LEAST 10mm TO AVOID FEATHER–EDGEING AND TO PROVIDE A SQUARE EDGE. BREAK OUT THE COMPLETE REPAIR AREA TO A MINIMUM DEPTH OF 50mm UP TO THE SAWN EDGE.
5. ENSURE AREA OF REPAIR IS CLEAN AND FREE OF DUST, UNSOUND OR CONTAMINATED MATERIAL, OIL, GREASE, CORROSION DEPOSITS.
6. PREPARATION AND PRIMING OF STEEL REINFORCEMENT

6.1. ANY CORRODED STEEL WITHIN THE REPAIR AREA IS TO BE FULLY EXPOSED AND REMOVE ALL LOOSE SCALE AND CORROSION DEPOSITS. STEEL TO BE CLEANED TO A BRIGHT CONDITION PAYING PARTICULAR ATTENTION TO THE BACK OF THE EXPOSED BARS ABRASIVE– BLASTING IS RECOMMENDED.

THE CONTRACTOR MUST ENSURE THAT CONSTRUCTION DUST IS KEPT TO A MINIMUM DURING THE REPAIR WORK AND MUST CONFORM TO HSE REGULATIONS REGARDING CONTROL AND EXPOSURE OF CONSTRUCTION DUST.

6.2. EXPOSED STEEL IS TO BE PRIMED USED ONE FULL COAT OF NITOPRIME ZINCRICH PLUS, OR SIMILAR, AND ALLOWED TO DRY AS PER THE MANUFACTURERS INSTRUCTION. A SECOND FULL COAT SHOULD BE APPLIED IF AREA'S OF THE EXPOSED STEEL REMAIN UNPRIMED AFTER THE FIRST APPLICATION.

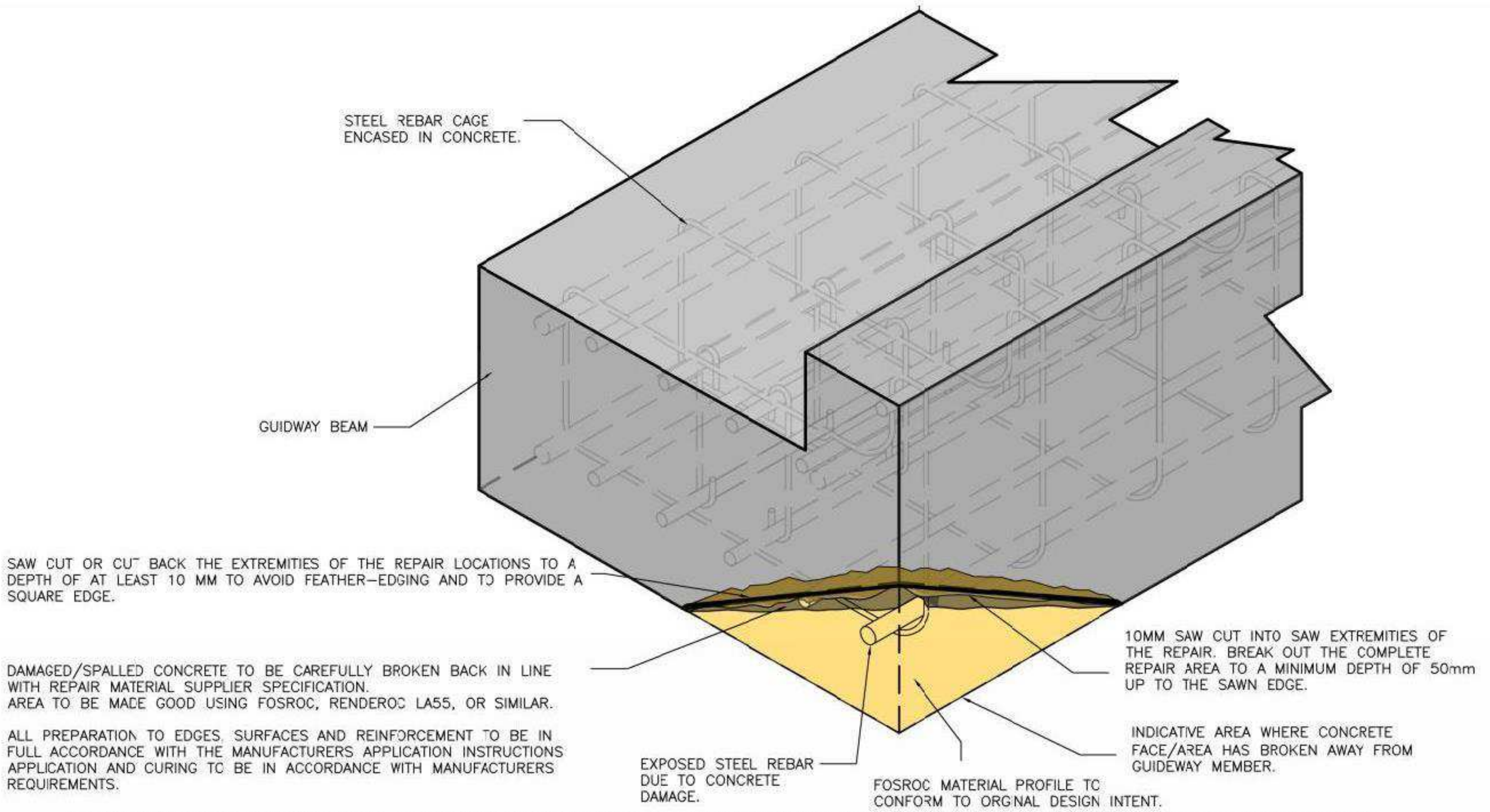
7. SUBSTRATE PRIMING

7.1. CONCRETE FACES/EDGES WITHIN THE REPAIR AREA IS TO BE CLEAN AND CLEAR OF DUST, GREASE, LOOSE, UNSOUND OR CONTAMINATED MATERIALS.

7.2. SUBSTRATE PRIMING AND APPLICATION OF THE CONCRETE REPAIR PRODUCT MUST BE IN STRICT ADHERENCE OF THE MANUFACTURERS INSTRUCTIONS.

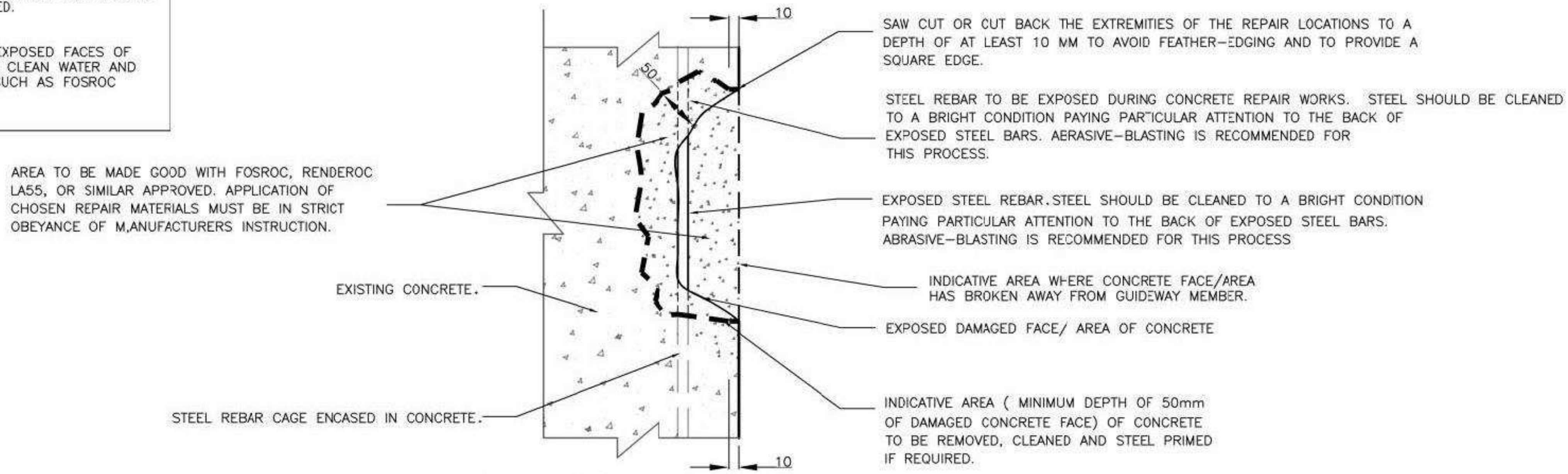
8. FORMWORK SHOULD BE LEFT IN PLACE UNTIL THE MINIMUM COMPRESSIVE STRENGTH STIPULATED BY THE SUPPLIER IS ACHIEVED.

9. IMMEDIATELY AFTER STRIKING THE FORMWORK, ALL EXPOSED FACES OF THE REPAIR SHOULD BE THOROUGHLY SOAKED WITH CLEAN WATER AND THEN SPRAYED WITH A LIQUID CURING MEMBRANE SUCH AS FOSROC CONCURE WB, OR SIMILAR APPROVED.



INDICATIVE ISOMETRIC VIEW ON GUIDEWAY BEAM SHOWING REINFORCEMENT AND POTENTIAL DAMAGE / SPALLING OF THE CONCRETE.

SCALE: 1:10



INDICATIVE REPAIR METHODOLOGY TO BE EMPLOYED

SCALE: 1:5

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DRAWING 6- REPAIRS TO DAMAGED / SPALLED CONCRETE AT LATERALS.

SCALE: AS STATED

APPENDIX I – FOUNDATIONS

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Ground conditions based on Capita interpretation of ground investigation data.
Non-compliance related to as-built as dug levels relative to original ground levels from long sections
Ground conditions encountered at foundation excavation from BAM000120015.pdf datasheets.
Foundation locations relate to those encountering sand and gravel in excavation and for NHBC depth assessment based on exploratory holes.

Chainage of 200 foundations underlain by sand and gravel for NHBC foundation depth assessment						
Nature Reserve	Swavesey to Longstanton	Longstanton to Oakington	Oakington to Histon	Histon to Arbury	Arbury to CRC	CRC to Milton
3051 to 3763	6283 to 10271	10465 to 13916	14013 to 17431	17530 to 18906	19011 to 19301	19415 to 20355
	7558	13249	14514	18591		20030
	7566	13264	14521	18636		20038
	7573	13271	14529	18643		20098
	7581	13279	14536	18651		20105
	7588	13286	14544	18658		20113
	7596	13294	14551	18666		
	7603	13301	14559	18673		
	7611	13309	14566	18681		
	7618	13316	14574	18688		
	7626	13324	14581	18696		
	7633	13339	14589	18703		
	7641	13346	14594	18711		
	7648	13376	14644	18718		
	7656	13384	14651	18726		
	7663	13391	14659	18733		
	7716	13421	14666	18741		
	7723	13436	14689	18748		
	7731	13444	14704	18756		
	7738	13459	14711	18763		
	7746	13474	14876	18771		
	7918	13481	14884	18778		
	7926	13489	14891	18838		
	7933	13504	15236	18846		
	7941	13511	15289	18853		
	7948	13519	15296			
	7956	13526	15319			
	7963	13536	15416			
	7971	13541	15469			
	7978	13546	15476			
	7986	13554	15601			
	7993	13561	15669			
	8106	13569	15714			
	8113	13576	15954			
	8128	13584	15969			
	8151	13591	15976			
	8158	13599	16279			
	8241	13606	16294			
	8248	13614	16301			
	8256	13756	16316			
	8263	13764	16324			
	8383	13771	16331			
	8391		16339			
	8398		16384			
	8443		16391			
	8451		16399			
	8458		16421			
	8466		16429			
	8473		16541			
	8481		16549			
	8488		16556			
	8496		16564			
	8503		16571			
	8511		16579			
	8518		16594			
	8526		16661			
	8533		16669			
	8541		16676			
	8548		16684			
	9561		16691			
	9576		16699			
	9711					
	9718					
	9726					
	9733					
	9741					
	9748					
	9756					
	9763					
	9771					
	9778					

Ground conditions based on Capita interpretation of ground investigation data.
Non-compliance related to as-built as dug levels relative to original ground levels from long sections
Non-complianse related to full NHBC depth requirements

Chainage of foundations assessed to be non-compliant to NHBC depth 1 of 2						
Nature Reserve	Swavesy to Longstanton					Longstanton to Oakington
3051 to 3763	6283 to 10271					10466 to 13916
3051	6336	6823	8076	8713	9516	11703
3058	6343	6831	8083	8721	9523	11756
3066	6351	6838	8091	8736	9531	11763
3073	6358	6846	8098	8743	9538	11996
3081	6366	6853	8106	8751	9546	12018
3088	6373	6861	8113	8758	9553	12026
3096	6381	6868	8121	8766	9568	12078
3103	6388	6876	8128	8773	9583	12086
3111	6396	6883	8136	8781	9591	12093
3118	6403	6891	8143	8788	9598	12101
3126	6411	6898	8151	8796	9606	12281
3156	6418	6906	8158	8803	9613	12288
3163	6426	6913	8166	8811	9621	12296
3171	6433	6921	8173	8863	9628	12303
3178	6441	6928	8181	8871	9636	12821
3186	6448	6936	8188	8878	9786	12829
3193	6456	6943	8196	8886	9793	12836
3201	6463	6951	8203	8893	9801	12844
3216	6471	6958	8211	8901	9808	12904
3223	6478	6966	8218	8938	9816	12911
3231	6486	6973	8226	8946	9823	12919
3328	6493	6981	8233	8953	9831	12934
3336	6501	6988	8241	8961	9838	13009
3343	6508	6996	8248	8968	9846	13016
3351	6516	7003	8256	8976	9891	13024
3358	6523	7011	8263	8983	9898	13031
3366	6531	7018	8271	9006	10016	13039
3373	6538	7026	8278	9013	10083	13046
3381	6546	7048	8286	9021	10091	13054
3388	6553	7551	8293	9028	10098	13861
3396	6561	7753	8301	9036	10121	13869
3403	6568	7761	8308	9043	10128	13891
3411	6573	7768	8316	9051	10136	13899
3418	6576	7776	8323	9058	10143	3 highlighted foundations identified in the Geotechnical Feedback Report as pile
3426	6583	7783	8331	9066	10151	
3433	6591	7791	8338	9073	10158	
3441	6598	7798	8346	9081	10166	
3448	6606	7806	8353	9088	10173	
3456	6613	7813	8361	9096	10181	
3463	6621	7821	8368	9103	10188	
3471	6628	7836	8376	9111	10196	
3478	6636	7843	8383	9118	10203	
3486	6643	7851	8391	9126	10218	
3493	6651	7858	8398	9133	10226	
3501	6658	7866	8406	9141	10233	
3508	6666	7873	8413	9148	10241	
3516	6673	7881	8421	9156	10256	
3523	6681	7888	8428	9163	10263	
3531	6688	7896	8436	9171	10271	
3538	6696	7903	8443	9178		
3546	6703	7911	8451	9186		
3553	6708	7918	8458	9193		
3561	6713	7926	8466	9201		
3568	6718	7933	8473	9208		
3576	6723	7941	8481	9216		
3583	6728	7948	8488	9223		
3591	6733	7956	8496	9231		
3598	6738	7963	8556	9238		
3606	6743	8001	8563	9246		
3613	6748	8008	8571	9253		
3621	6753	8016	8578	9261		
3628	6758	8023	8601	9268		
3636	6763	8031	8616	9276		
3658	6771	8038	8661	9463		
3703	6778	8043	8668	9471		
3733	6786	8048	8676	9478		
3741	6793	8053	8683	9486		
3748	6801	8058	8691	9493		
	6808	8063	8698	9501		
	6816	8068	8706	9508		

Ground conditions based on Capita interpretation of ground investigation data.
Non-compliance related to as-built as dug levels relative to original ground levels from long sections
Non-complianse related to full NHBC depth requirements
Risk related to and assessment of depth short of full NHBC depth and soil plasticity.

Chainage of foundations assessed to be non-compliant to NHBC depth 2 of 2							
Oakington to Histon			Histon to Arbury			Arbury to CRC	CRC to Milton
14014 to 17431			17531 to 18906			19011 to 19301	19415 to 20355
14014	15946	17271	17531	18118	18906	19011	19425
14019	15961	17279	17536	18126		19019	19470
14024	15984	17286	17541	18133		19026	19483
14029	15991	17294	17548	18141		19034	19498
14034	15999	17311	17556	18148		19041	19505
14049	16006	17326	17563	18156		19049	19513
14064	16014	17331	17571	18163		19056	19520
14079	16029	17336	17578	18171		19064	19528
14086	16036	17341	17586	18178		19071	19580
14094	16044	17346	17593	18186		19079	19588
14101	16051	17351	17601	18193		19086	19595
14109	16056	17356	17608	18201		19094	19603
14124	16061	17361	17616	18208		19101	19610
14236	16069	17369	17623	18216		19109	19625
14244	16076	17376	17631	18223		19116	19648
14266	16091	17426	17638	18231		19124	19670
14274	16099	17431	17646	18238		19131	19700
14296	16106		17721	18246		19139	19708
14304	16121		17728	18253		19146	19730
14311	16129		17736	18261		19154	19745
14319	16136		17743	18268		19161	19775
14326	16144		17751	18276		19169	19798
14341	16151		17758	18283		19176	19805
14356	16159		17766	18291		19184	19813
14364	16166		17773	18298		19191	19820
14379	16174		17781	18306		19199	19828
14386	16181		17788	18313		19206	19835
14394	16189		17796	18321		19214	19850
14401	16196		17803	18328		19221	19858
14409	16204		17811	18343		19229	19880
14416	16406		17818	18351		19236	19888
14424	16414		17826	18358		19244	19895
14431	16436		17833	18366		19251	19903
15484	16444		17841	18373		19259	19910
15489	16451		17848	18381		19266	19918
15494	16459		17856	18388		19274	19925
15586	16466		17863	18396		19281	19933
15594	16474		17871	18403		19286	19940
15609	16481		17878	18411		19291	19948
15616	16489		17886	18418		19296	19955
15624	16496		17893	18426		19301	19963
15631	16504		17901	18433			19970
15639	16511		17908	18441			19978
15654	16601		17916	18448			19985
15661	16609		17923	18456			19993
15676	16616		17931	18463			20000
15691	16624		17938	18471			20008
15706	16631		17946	18478			20210
15721	16639		17953	18486			20240
15729	16736		17961	18493			20248
15744	16744		17968	18523			20275
15751	16819		17976	18531			20355
15766	16826		17983	18546			
15774	16834		17991	18553			
15781	16841		17998	18561			
15789	16849		18006	18576			
15796	16856		18013	18583			
15804	16864		18021	18598			
15811	16871		18028	18606			
15819	16946		18036	18613			
15826	16954		18043	18621			
15834	17044		18051	18628			
15841	17051		18058	18808			
15864	17059		18066	18816			
15901	17066		18073	18823			
15909	17074		18081	18831			
15916	17081		18088	18876			
15924	17089		18096	18883			
15931	17101		18103	18891			
15939	17264		18111	18898			